NOTES ON THE CHICAGO, MILWAUKEE & ST. PAUL RAILWAY ELECTRIFICATION

By R. Beeuwkes
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The electrified territory of the Chicago, Milwaukee & St. Paul Railway Company now extends from Harlowton, Mont., to Avery, Ida., and from Othello to Tacoma, Wash., a total distance of 645 route miles, or of about one-third more track miles.

The first portion to be put into electrical operation was that between Three Forks and Deer Lodge, the west sub-division of the Rocky Mountain division. This was in December of 1915. The second portion, Three Forks to Harlowton, the east sub-division of the Rocky Mountain division, began to be electrically operated in April of 1916, and the section from Deer Lodge to Avery, the Missoula division, in November and December of 1916.

Electric helper service was installed on the Saddle Mountains, west of Othello, in August of 1919, and on the Cascade Mountains in November of the same year. Electric road freight service is being installed as rapidly as the conversion, by change of gear ratio, of the original passenger locomotives of the Rocky Mountain and Missoula divisions into freight locomotives will permit. Regular electric passenger service west of Othello was started in March of this year. This section now comprises the west sub-division of the Columbia division, extending from Othello to Cle Elum, and the Coast division extending from Cle Elum to Tacoma and Seattle, two engine divisions, but the entire district will shortly be merged into and operated as one electrified division.

The following general notes regarding some of the items of a list suggested as representing matters of particular interest in connection with electrification work are based on experience with the above installations.

First Costs

The electrification work on the Rocky Mountain and Missoula division was carried on during the years 1914, '15 and '16, when labor and material conditions were comparatively stable and arrangements for the supply of both could be made in such a way as to avoid the delays to which the work west of Othello, carried on largely during the war, was more or less subject. Costs for the former work was therefore believed to be the more capable of application of the necessary corrective factors corresponding to present and other assumed price standards, and approximate figures are given below:

Route miles.. 438
Actual mileage transmission line.............................. 364
Total kw. capacity of sub-stations.......................... 59,500
Number of locomotives: 12 passenger, 30 freight and 2 switching locomotives.
Number of sub-stations, 14. Two operators' buildings at each station.
Automatic signals: Existing battery fed track circuit and semaphore signals were replaced with alternating current light signals fed from a 4,400 volt primary circuit connected to sub-stations; costs not included.

Item	Avg. Cost per Route Mile	Various Avg. Unit Costs	Per Cent Item Cost to Total, Excelled Locos.
Trolley system complete..............	$ 8,390		47.7
Transmission system complete.........	2,360		13.5
Per mile of transmission line........		$ 2,835.00	
Substation layout complete...........	6,050		34.4
Per station..........................		189,400.00	
Per kw.		45.00	
Sub-station building and grounds:			
Per station..........................		38,400.00	
Per kw.		9.50	
Operators' dwellings, etc.:			
Per station..........................		6,100.00	
Per kw.		1.50	
Sub-station apparatus:			
Per station..........................		144,900.00	
Per kw.		34.00	
Miscellaneous, including right-of-way, changes in telegraph and telephone lines to clear transmission and trolley, storehouses, minor apparatus at shops and round houses, etc.	265		1.7
Engineering and administration, except that for drafting and inspection for sub-stations, charged direct....................	514		2.9
Locomotives, including transportation, messenger and miscellaneous charges:			
Per road locomotive..................		122,500.00	
Per switching locomotive.............		37,700.00	
Total per route mile, excluding locomotives..........................	17,579		100.00

The above figures, without a detailed knowledge of the labor and material figures on which they are based, would, of course, be of only very rough value in estimating the costs of electrification in other cases, and their main purpose is to give an approximate idea of the relative importance, from a cost standpoint, of the different items involved.

Some Comparative Operating Costs of Electrified and Steam Operated divisions

The following tabulation indicates, as between the electrified Rocky Mountain and Missoula divisions and the adjacent steam operated divisions, the relative magnitude of the more important items of freight operating expense which are affected by the type of motive power employed, costs for the Missoula division being taken as unity. The figures apply for the last six months of the year 1918, this period being taken due to the fact that the data had already been worked up for other purposes and were therefore most readily available.

Item	Columbia Division	Idaho Division	Missoula Division	Rocky Mt. Division	Musselshell Division
Steam or electric locomotive repairs..........................	1.97	2.34	1.00	.86	2.26
Train conductors and brakemen....	2.78	3.05	1.00	1.46	1.61
Train enginemen and motormen......	1.84	2.17	1.00	1.30	1.21
Train locomotive fuel or power...	2.05	2.34	1.00	1.04	1.38
Engine-house expense, train.......	3.15	2.50	1.00	.80	3.71
Total yard service*	.78	1.12	1.00	.99	.71
Total of items of expense affected by type of motive power **..	1.67	1.90	1.00	1.11	1.33

*In 1918 a considerable portion of the switching was still done by steam, sufficient electric switching locomotives not having yet been received.
**Includes superintendence, maintenance of sub-stations, transmission and trolley systems water and fuel stations, shops and engine-houses; also locomotive and train supplies, in addition to the items for which individual comparison is given in the tabulation.

In considering the above it should be noted, as shown on the attached profile, that the Musselshell division is of low grade, maximum 0.4 per cent, while the Rocky Mountain division, crossing both the Belt and Rocky mountain ranges, and formerly under steam operation, constituting "The neck of the bottle," as far as operation was concerned, has long mountain grades of 1.7 and 2.0 per cent.

The Missoula division, crossing the Bitter Root Mountains with long 1.7 per cent grades, would not from the profile appear to involve as difficult operating problems as the Columbia division with its long 2.2 per cent grade on the east slope of the Saddle Mountains and its comparatively long 1.6 per cent grade on the west slope, but the much more unfavorable weather and topographical conditions existing on the Missoula division more than offset the difference in grades.

Some of the more prominent reasons for the advantageous results secured under electrical operation are as follows:-

Cost of engine repairs per thousand-ton milesis much decreased, due to the fact that not only is the cost of repairs per engine mile of the electric locomotive much less than that of the average steam locomotive replaced, but the number of engine miles per thousand-ton miles is, on account of the greater capacity of the electric locomotive, much less. The engine miles per thousand-ton miles for the Missoula division under electric operation in the 1918 period taken above were only about 55 per cent of those of the latter half of 1915 under steam operation.

Train conductor and brakemen expense per thousand-ton miles is reduced under electrical operation due to increased ton miles per train mile and increased train speed. This item, for the Missoula division for the 1918 period, was about 9 or 10 per cent less than of the 1915 steam period, while for the Idaho and Columbia divisions, still operated by steam, the expense per thousand-ton miles more than doubled.

Enginemen's expense decreases under electrical operation, due to the same causes which decrease trainmen's expense. For the Missoula division this item increased only a few per cent for the 1918 period as compared with the 1915 period, while for the Idaho and Columbia divisions it practically doubled.

Recapitulation of "Passenger Train Performance," Showing Delays to Passenger Trains on the Basis of Miles of Line Operated; Lines West of Mobridge; Months October, November and December, 1919, and January, February and March, 1920

	DELAYED TIME IN MINUTES PER MILE OF LINE OPERATED				
Division	Mobridge to Marmarth	Marmarth to Harlowton	Harlowton to Avery	Avery to Cle Elum	Cle Elum * to Seattle
Motive Power	Steam	Steam	Electricity	Steam	Steam
Miles	190	340	437	325	90
Item					
1. Meeting and blocked behind passenger	18.83	11.33	15.15	10.33	12.60
2. Meeting and blocked behind freight	14.03	5.58	6.49	1.98	2.89
3. Extra cars	1.33	0.58	0.02	2.35	1.37
4. Excess time switching	1.35	2.69	2.16	1.54	4.51
5. Electric block signals	0	0.13	9.52	4.07	10.62
6. Slow orders	4.54	1.37	1.29	0.83	5.38
7. Bad weather and poor coal	109.2	13.59	3.53	3.48	4.91
8. Engine condition	20.92	25.20	11.43	9.39	10.54
9. Accidents and derailments due to engine	2.63	2.25	0.15	3.85	2.05
10. Trolley and substation	0	0	3.93	0.03	0
11. Total of items 1 to 10 inclusive, which are affected by the type of motive power used	172.65	62.95	52.73	35.34	54.93
12. Average of items 1 to 10 inclusive, for the four steam divisions 74.75					
13. Awaiting connections	0	1.16	0.02	1.82	1.94
14. Handling extra heavy bag mail and express	6.79	3.26	2.09	1.20	0.97
15. Extra stops for passengers and railway crossings	0.92	0.97	1.99	0.22	1.13
16. Car conditions	8.63	18.05	9.75	6.87	6.10
17. Accidents and derailments not due to engine	27.69	12.51	17.75	14.63	30.49
18. Slides, earth, rock and snow	2.53	0	3.64	3.86	13.80
19. All other causes	11.30	1.78	11.03	4.91	9.95
20. Total of items 13 to 19 inclusive, which are not affected by the type of motive power	57.80	37.85	46.30	33.86	103.69
21. Average of items 13 to 19 inclusive, for the four steam divisions 46.77					
22. Total of all items	230.45	100.80	99.03	69.20	158.62
23. Average of all items for the four steam divisions 121.52					
24. Minutes lost on schedule running time per mile of line operated	205.5	69.7	8.94	0.00	162.2
25. Minutes made up per mile of line operated	46.6	35.6	100.00	81.00	11.54

*Electrical operation commenced in March.

Regarding items of train locomotive fuel, it should be stated that the factors given are based not on the actual cost of fuel for the particular divisions involved, but on the average fuel price for the system. Cost of fuel haul is not taken into account.

The above is, at best, only an incomplete statement of some of the more direct benefits derived from electrical operation. Constant improvement is to be expected as further advantages are recognized and developed through operating experience.

Reliability of Service

The question of the relative reliability of steam and electrical operation is one that is frequently raised, and it is believed the "Recapitulation of Passenger Train Performance" shown below, will be of interest in this connection.

The recapitulation gives the delays to passenger trains, on basis of miles of line operated, for the various railway divisions of the Milwaukee, west of Mobridge. Similar information is not conveniently available for freight train performance, but delays to freight service would naturally be reflected in the passenger train performance.

It will be noted from Item 11 that the electrically operated territory shows less time delayed than any of the steam operated divisions, except that between Avery and Cle Elum, a district particularly favored as regards its freedom from climatic, topographical and other conditions, which tend to cause delays. Attention is also called to the favorable showing, for electricity, of Items 24 and 25.

Conclusion

In conclusion this hastily prepared and, therefore, superficial statement regarding some of the facts of the Milwaukee electrification, I believe it may be said that in no respect have the results of the electrification failed to equal the expectations of the railway organization, and in most respects these expectations have been far exceeded. The extent of the electrification is such as to leave no doubt as to the practicability of indefinite expansion with an assurance of increased reliability and safety and a marked determinable increase in capacity. Items of operating expense dependent on whether steam or electricity is used as a motive power, we have found by experience and estimates to be so reduced and the benefits indirectly obtained to be so great as to render justifiable, even with the increased investment charges, the serious consideration of indefinite extension of electrification, even for lighter grades.

tional investment except the necessary local distributing system. The high tension bus line could be used for the transfer of power from one part of the power company's system to another and in some cases for an interchange connection between power companies operating in adjacent territories.

Indeed, there is no reason why the power company should not own and operate the railroad sub-stations entirely, selling power to the railroad in the form required by it, and delivering directly to its trolley wire.

This would cut the railroad's investment to that required to cover overhead construction and rail bonds. The necessary electric locomotives should not be charged against electrification, because a railroad must buy locomotives whether it electrifies or not, and electric locomotives cost no more than steam locomotives for the same service. It is true they cost more per unit and more per ton, but they can do so much more work that a smaller number are required for any particular service.

Shifting a part of the investment from the railroad to the power company will, of course, necessitate a higher rate for power. It should be immaterial to the railroad whether the expense is met in the form of fixed and operating charges on equipment or in the form of an increased power bill. The decreased original investment required of the railroad should, however, be an important factor in most cases, and should facilitate the promotion of any electrification project.

A railroad favorably situated can make a contract with a power company for power to be delivered to its sub-stations or to its trolley wire, as the case may be, whereas it might have great difficulty in borrowing the money necessary to build the lines and sub-stations required to distribute and transform its own power. One reason for this is that railroad earnings have been kept down by regulation to a point where only a few of the most fortunate roads have been able to show an attractive return on their investment, and the average railroad security therefore is not held in very high esteem.

The best security an investor can hope for, in case his money is used for railroad electrification, is a first mortgage on the property. On the other hand, if the same money goes into the same physical investment, but the investment is made by a power company on the strength of a contract with the railroad, then the money so invested has a claim against the earnings of the railroad underlying even that of the road's first mortgage bonds. A railroad can run without paying its bond interest, but it cannot run without power.

Power Rates

Rates will generally be based on the cost of service and must be figured closely, for the railroads in order to warrant the expenditure required for an electrification project, must be assured of a very material saving in operating expenses.

A rate should be flexible enough to allow quite a wide variation in the amount of power taken and in the load factor, without penalizing the railroad to such an extent that it will restrict its operations in order to save on power.

The ideal rate, from the railroad point of view, is a straight kilowatt-hour rate. No attention need then be paid to peak loads, and the system can be operated with a minimum of judgment and care. Such a rate is hardly feasible from the power company's standpoint, however, for if peak loads can be taken without let, hindrance or compensation, such loads at times might prove burdensome. A reasonable compromise can be reached by basing the major part of the charge on the amount of energy taken, but with a small maximum demand charge, just sufficient to offer an incentive to the railroad to keep its demand as low as good operating conditions will permit. It can also be shown that such a rate is

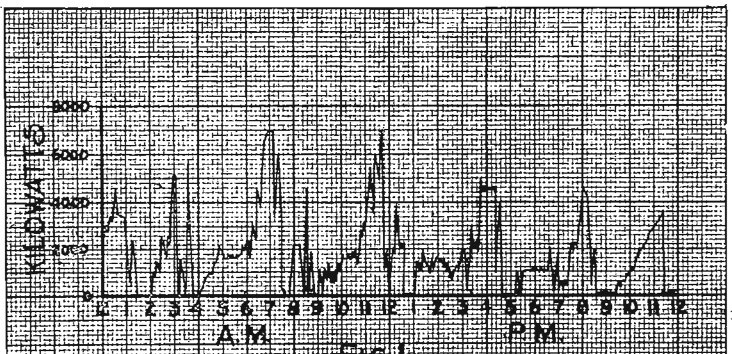

FIG. 1

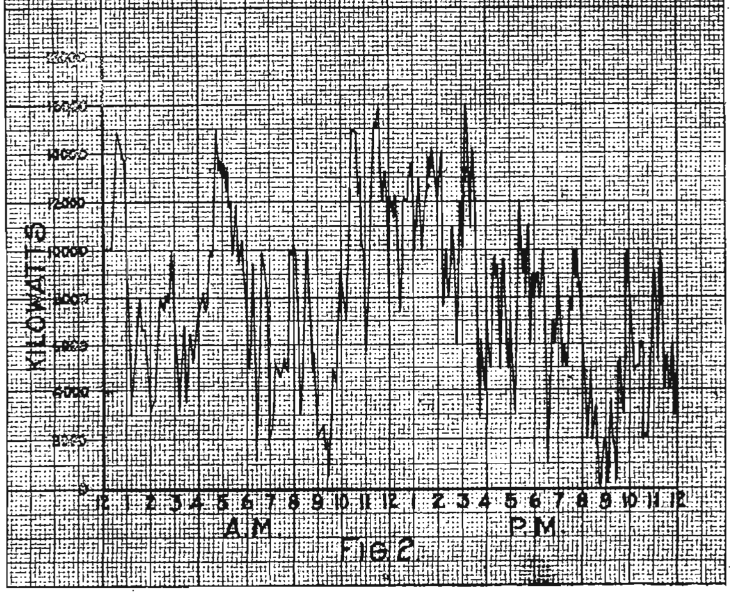

FIG. 2

not at all inconsistent with the average power company's costs, based on an analysis of the investment required for furnishing continuous power and peak loads respectively, and taking into consideration the relation between load factor and diversity factor.

Operating Features

Perhaps the most prominent characteristic of a railroad load such as that of the C., M. & St. P. or the B., A. & P. is its lack of any outstanding characteristic. The two electrified divisions of the former road take peak loads of about 15,000-kw. each, and the B., A. & P. takes about 8,000 kw. These peak loads do not come at the same time, as a general thing, and the fact that they exist is ascertained by referring to the records rather than by any physical effect which they have on the power system. The power factor is about unity and the load is so scattered around and fed by different lines that fluctuations in railroad load have practically no effect on voltage regulation.

A typical daily load curve of one of the substations on the Rocky Mountain division of the C., M. & St. P. Railway is shown in Fig. 1. The load factor of the load shown is 20 per cent. Fig. 2 shows the daily load of this entire division. The load factor is 50 per cent. The Missoula division of the same road takes a very similar load, as does the B., A. & P. railway, except that the latter peaks at about 8,000 kw., and has a load factor of 30 per cent. Taking the three loads together, however, the total load factor is higher than that of any of the constituent parts, and combining the total railway load with that of the balance of the Montana Power Company's system makes a total with a daily load factor which frequently exceeds 90 per cent, typical figures at the present time being 144,000 kw. average and 160,000 kw. maximum.

The variations in load during the year are small, as the following figures will show:

Month	Kilowatt Hours
January	6,426,072
February	4,650,737
March	5,835,682
April	5,984,101
May	5,836,298
June	5,693,656
July	5,771,099
August	5,689,684
September	5,930,394
October	6,252,995
November	5,127,079
December	5,846,664
Total	69,044,461
Mean Month	5,753,705
Maximum Month	6,426,072

As shown above, the maximum energy consumption per month shows a variation from the mean of only 12 per cent.

Before the railroad load was taken on the Montana Power Company's system, some slight apprehension was felt on the part of the railroads as to the ability of the power company to meet satisfactorily all the requirements of the roads, as to regulation and continuity of service. The power company also had some slight misgivings as to the effect on its system of such a widely fluctuating load as that of the railroads was supposed to be.

Operation was started and nothing out of the way happened. Operation has continued for the last five years and any trouble of consequence due to the use of electric power has yet to be experienced either by the railroads or by the power company.

Altogether, it is safe to say that railroad electrification constitutes one of the most satisfactory applications of electric power.

Notes on the Chicago, Milwaukee & St. Paul Railway Electrification

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2. Meeting and blocked behind freight	14.03	5.88	6.49	1.98	2.89
3. Extra cars	1.33	0.58	0.02	2.35	1.37
4. Excess time switching	1.35	2.69	2.16	1.54	4.51
5. Electric block signals	0	0.13	9.52	4.07	10.62
6. Slow orders	4.54	1.37	1.29	0.33	5.38
7. Bad weather and poor coal	109.2	13.59	3.53	3.48	4.91
8. Engine condition	20.92	25.20	11.43	9.39	10.54
9. Accidents and derailments due to engine	2.63	2.25	0.15	3.85	2.05
10. Trolley and substation	0	0	3.93	0.03	0
11. Total of items 1 to 10 inclusive, which are affected by the type of motive power used	172.65	62.95	52.73	35.34	54.93
12. Average of items 1 to 10 inclusive, for the four steam divisions ... 74.75					
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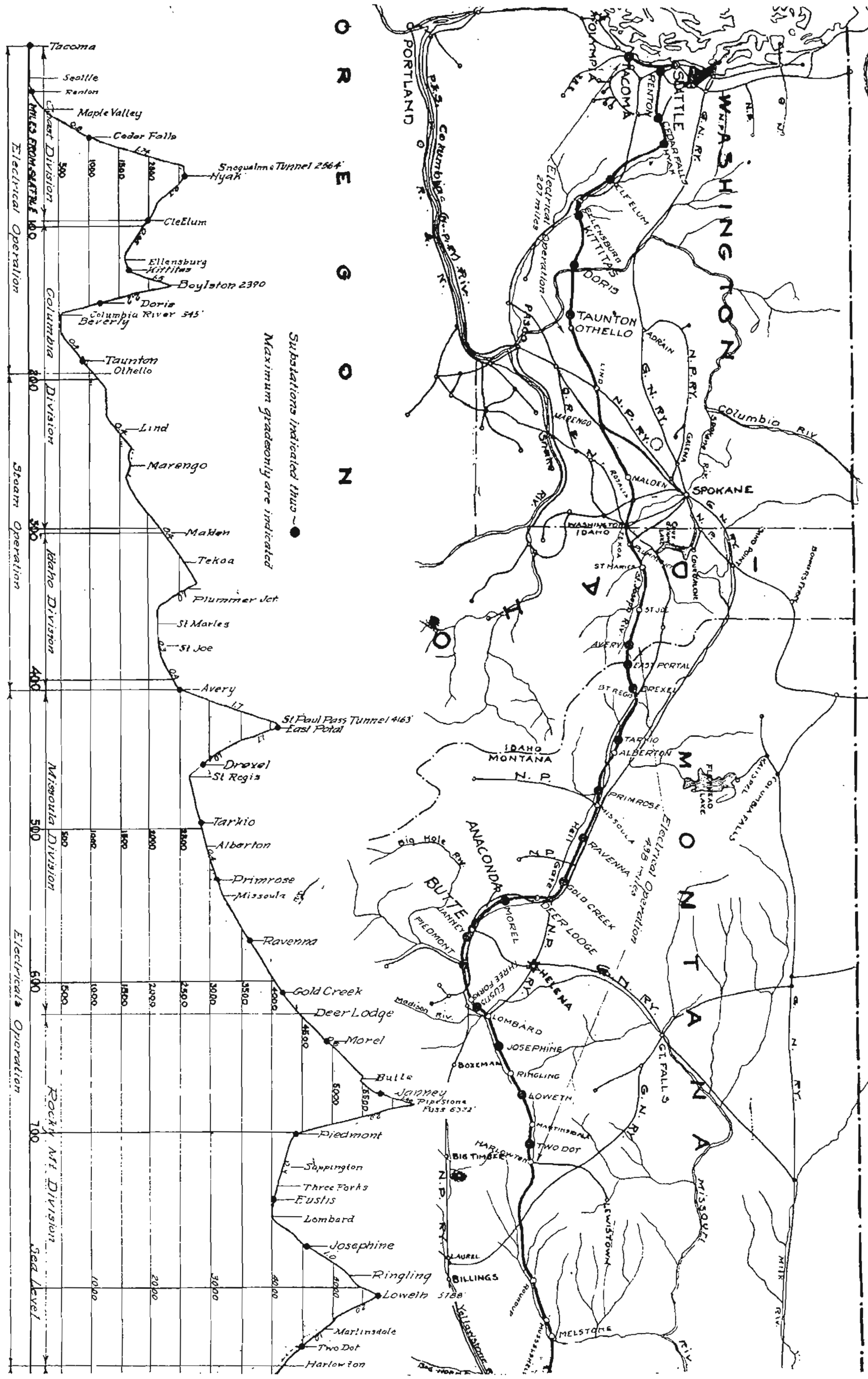
24. Minutes lost on schedule running time per mile of line operated	205.5	69.7	8.94	0.00	162.2
25. Minutes made up per mile of line operated	46.6	35.6	100.00	81.00	11.54

*Electrical operation commenced in March.

[illegible]


Tacoma
Seattle
Renton
Maple Valley
Cedar Falls
Snoqualmie Tunnel 2864'
Hyak
CleElum
Ellensburg
Kittitas
Boylston 2390
Doris
Columbia River 545'
Beverly
Taunton
Othello
Lind
Marengo
Malden
Tekoa
Plummer Jct.
St Marles
St Joe
Avery
St Paul Pass Tunnel 4163'
East Potal
Drexel
St Regis
Tarkio
Alberton
Primrose
Missoula
Ravenna
Gold Creek
Deer Lodge
Morel
Butte
Janney
Pipestone Pass 6372'
Piedmont
Sappington
Three Forks
Eustis
Lombard
Josephine
Ringling
Loweth 5788'
Martinsdale
Two Dot
Harlowton
Miles from Seattle
Coast Division
Columbia Division
Idaho Division
Missoula Division
Rocky Mt. Division
Electrical Operation
Steam Operation
Sea Level
Substations indicated thus
Maximum grades only are indicated
OREGON
WASHINGTON
IDAHO
MONTANA
CANADA
PORTLAND
OLYMPIA
TACOMA
SEATTLE
KENTON
CEDAR FALLS
HYAK
CLE ELUM
ELLENSBURG
KITTITAS
DORIS
TAUNTON
OTHELLO
ADRAIN
LIND
MARENGO
MALDEN
SPOKANE
ROSALIA
ST MARIES
ST JOE
AVERY
EAST PORTAL
ST REGIS
DREXEL
TARKIO
ALBERTON
PRIMROSE
MISSOULA
RAVENNA
GOLD CREEK
DEER LODGE
ANACONDA
BUTTE
JANNEY
PIEDMONT
MOREL
HELENA
THREE FORKS
EUSTIS
LOMBARD
JOSEPHINE
BOZEMAN
RINGLING
LOWETH
MARTINSDALE
TWO DOT
HARLOWTON
BIG TIMBER
LEWISTOWN
LAUREL
BILLINGS
MELSTONE
GT. FALLS
FLATHEAD LAKE
KALISPELL
Electrical Operation 207 miles
Electrical Operation 438 miles
Columbia Riv.
Big Hole Riv.
Madison Riv.
Missouri
Yellowstone
G. N. RY.
N. P. RY.
N. P.
O. R. & N.
Columbia (S.P.&S.) Riv.
IDAHO
MONTANA
WASHINGTON
IDAHO

of the steam operated divisions, except that between Avery and Cle Elum, a district particularly favored as regards its freedom from climatic, topographical and other conditions which tend to cause delays. Atttention is also called to the favorable showing, for electricity, of items 24 and 25.

Conclusion

In concluding this hastily prepared and, therefore, superficial statement regarding some of the facts of the Milwaukee electrification, I believe it may be said that in no respect have the results of the electrification failed to equal the expectations of the railway organization, and in most respects these expectations have been far exceeded. The extent of the electrification is such as to leave no doubt as to the practicability of indefinite expansion with an assurance of increased reliability and safety and a marked and determinable increase in capacity. Items of operating expense dependent on whether steam or electricity is used as a motive power, we have found by experience and estimates to be so reduced and the benefits indirectly obtained to be so great as to render justifiable, even with the increased investment charges, the serious consideration of indefinite extension of electrification, even for lighter grades.

Electric Operation on the Butte, Anaconda & Pacific Railway

By F. W. Bellinger

Electrical Superintendent, Butte, Anaconda & Pacific Railway

The Butte, Anaconda & Pacific Railway was built in the year 1892, principally for transfer service between the Anaconda Copper Mining Company's mines in Butte and smelter at Anaconda. The tracks connecting these two cities are approximately twenty-six miles long, but the yards and sidings included in the present electrification bring the total mileage up to one hundred twenty.

Until the Butte, Anaconda & Pacific Railway Company decided upon the electrification of its lines for reasons of economy, it is doubtful if this step had been taken by any steam railroad for that reason, although various steam roads had been electrified for the purpose of obviating some special condition, such as smoke nuisance in tunnels or cities, congested terminals, or to accomplish some special work for which a steam engine was not adapted.

Work on the electrification was begun in the spring of 1912, and regular operation was commenced eighteen months later. Direct current at 2,400 volts was used.

Seventeen electric locomotives operating in pairs replaced twenty-eight steam engines of the mastodon type, and a substantial reduction, both in the number of crews required and in the amount of overtime worked, was effected.

Power is taken from The Montana Power Company's sub-stations at Butte and Anaconda. The advantage of purchasing electric power from this large operating company, instead of developing the required power independently, was readily apparent in the case of the Butte, Anaconda & Pacific Railway Company. The road was relieved of all first cost of development and transmission of power and all operating expense up to the point of delivery at the two sub-stations. The Butte sub-station is equipped with three 1,000-kw. motor-generator sets, exciter units and switchboard appurtenances, while at Anaconda the sub-station is equipped similarly with the exception of having four 1,000-kw. motor-generator sets.

The railway company makes every effort to operate its sub-stations at as high a load factor as possible and at a leading power factor. Under favorable conditions it is possible to make a 42 per cent load factor. The nature of the haul on this line is such as to make it impossible to dispatch all trains, although good results are generally obtained, even in the switching service, by the cooperation of the yardmasters.

On our main-line freight service between East Anaconda and Rocker, a distance of 20.1 miles, the standard train, west bound, that had been handled with steam was 50 cars, aggregating 3,500 tons, and the average running time for such a train, where no stops were made, was about one and one-half hours, corresponding to an average speed of approximately 13.4 miles per hour. The electric locomotives now haul a trailing load of 4,600 tons, at a speed of 16 miles per hour.

On the Smelter Hill line, a length of approximately seven miles with a grade of 1.1 per cent, 25 ore cars, averaging 70 tons each and making a trailing load of 1,750 tons, form a drag. The round trip is made in about one hour, thus making it possible to make eight round trips per day, or a delivery of 200 cars in ten hours. As compared with this, a steam engine handled, under favorable conditions, 16 cars, or a trailing load of 1,120 tons, and made six round trips in ten hours, or a delivery of 96 cars per day. Therefore, we have now an increase of 108 per cent in this particular service, using the same crew and working the same number of hours as previously.

A comparative statement showing the cars handled per day for the months of April, 1917-1918, is as follows:

	1917	1918
Cars per day	1,043	866
Tons per day	44,597	37,917
Tons per train, east	1,449	1,560
Tons per train, west	4,198	4,625
Tons per train, average	2,797	3,098