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THE ELECTRIFICATION OF TRUNK LINES

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141 It is assumed from a physical and mechanical viewpoint, that electric traction can meet all the demands and requirements of railroad service. Therefore, whether electricity will replace steam traction or not is entirely a commercial problem.

THE COMMON DENOMINATOR = COMMERCIAL CONSIDERATIONS[1]

142 It may be stated at the outset that whatever system of electrification is adopted, a very large outlay has to be faced and no case for electrification can be made out unless an increase in net receipts can be secured more than sufficient to pay interest on the extra capital involved. This increase may be brought about either by decreasing the working expenses for the same service, by so modifying the service as to bring in a greater revenue, or by a combination of these.

143 However, there is hardly a steam road in existence today which does not have divisions or sections, where distinctly local traffic can be handled more profitably by light, comparatively frequent electric service, than as now, with heavy steam trains. Steam and electric service can be operated over the same tracks without

[1] Commenting on the problem of electrification of the Central Pacific over the Sierras, Mr. Kruttschnitt says: "Eastern critics may be inclined to the opinion that we are dallying with this matter. We have found that it pays well to make haste slowly with regard to innovations. Electrification for mountain traffic does not carry the same appeal that it did two years ago. Oil burning locomotives are solving the problem very satisfactorily. Each Mallet compound locomotive, having a horsepower in excess of 3,000, hauls as great a load as two of former types, burning 10 per cent less fuel and consuming 50 per cent less water."—*Wall Street Journal.*

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detriment or embarrassment to either. In so doing each kind of service would be appropriately handled in a manner best suited to the conditions of each.

144 The fundamental principle, based on the present state of the art, seems to be that if you cannot accomplish something by means of electricity that is now impossible by steam traction, there is nothing to justify the change; the mere substitution of one kind of power for another, merely to obtain the same result, is not commercially warranted.

145 There are certain inherent advantages in electrical operation that have shown up very well, because the increase in business has absorbed the increased interest account, but these cases hardly apply to trunk line conditions, as the law of induced travel has no bearing on freight train operation, the principal business of trunk line roads.

146 In heavy work the limiting feature of the steam locomotive is the boiler, and the maximum adhesion can be utilized only at low speeds. For example, a 2-8-0 locomotive with 180,000 lb. on the drivers, has a tractive force, at 10 miles per hour, of about 40,000 lb. or 4.5 to 1. At 30 miles per hour the tractive force becomes 13,250 lb. or 30.2 to 1. As tractive force governs the tonnage hauled, the ability of the electric locomotive to utilize almost indefinitely power proportional to the maximum adhesion and produce a drawbar pull entirely independent of the critical speed of a steam locomotive, as limited by the boiler, is a marked feature.

147 In heavy grade work the ability to increase the speed shows up favorably to the electric locomotive as enlarging the capacity of a given section, but here also the business has to be sufficient to absorb the increase in fixed charges.

148 With steam locomotives a coal consumption, when running, of 4 to 5 lb. per i.h.p-hr. really means 6 or 7 lb. at the rail, when the losses due to firing up, laying by in yards and sidings, blowing off at the pops, and consumption of the air pumps, are taken into account. Whereas, under electric operation, with an efficiency of 65 to 70 per cent between the power house and the rail, a coal consumption of 4 lb. per kilowatt hour at the rail can be counted on.

149 The writer is informed that the Metropolitan Street Railway station (1903) with a 40 per cent load factor, produced power, at the switchboard, at the rate of 4.7 mills per kilowatt hour (or 3.5 mills per horsepower hour), and with a load factor of 55 per cent which prevails in the winter time, the cost is at the rate of 4.43 and 3.3

mills respectively. These costs cover all expenses and repairs except fixed charges. The coal consumption is 2.9 lb. per kilowatt and 2.16 lb. per horsepower hour.

150 L. B. Stillwell is authority for the statement that the Interborough is producing power at the rate of 2.6 lb. of coal per kilowatt hr. or 3 lb. at the drawbar.

151 Another authority gives the following figures for the elevated roads for cost of power, $0.005 per kilowatt hour at the switchboard, $0.0066 at the third rail shoes, or $0.0089 at the rims of the drivers. These figures are exceptional and hard to duplicate and as the fixed charges are not included, the writer would consider 1¼ cents per kilowatt hour at the rail a conservative figure, and will use this cost in the following computations.

RELATIVE COST OF COAL FOR STEAM AND ELECTRIC OPERATION

152 It may be fair to assume that where average coal is used, we can count on about $2.25 per ton for locomotive coal on the tender, while a much cheaper grade can be used in the power house, costing, with modern coal handling facilities, about $1.50 per ton. At this rate the relative difference in the cost of coal at the rail would be represented by the following figures:

Electric power station $\frac{2.5\text{ lb.}}{50\%\text{ eff.}} \times \$1.50$	$7.50
Steam locomotive $7 \times \$2.25$	$15.75

or 50 per cent in favor of electricity. The following results of the Mersey Tunnel operation are pertinent: Under electric operation one ton of coal at $2.10 yields 2.29 ton miles at 22½ miles per hour, while with steam, one ton of coal at $3.84 yields 2.21 ton miles at 17¾ miles per hour. The difference amounting to 55 per cent is in favor of the electric operation, thus:

$$\left[1 - \frac{2.10}{3.84}\right] \times \frac{22.5}{2.29} \div \frac{17.75}{2.21} = \left[1 - \frac{2.10}{3.84}\right] \times \frac{22.5 \times 2.21}{2.29 \times 17.75} = 55\%$$

153 On mountain grades or in heavy freight service, where the boiler of the freight locomotive is forced to the limit, and the boilers are designed for this particular purpose, the showing is still more favorable to the electric side. Especially is this true when the steam locomotive is detained on side tracks for as long a period as it takes to make the run, which is very frequently the case, since under

these conditions the cost for fuel becomes a larger proportion of the total operating expense. A 2-8-0 locomotive with 50 sq. ft. of grate surface burns 300 lb. of coal per hour while lying on side tracks. Reports from Mallet locomotives indicate that from 600 to 800 lb. are burned per hour under the same conditions.

154 The cost of a unit of power with the steam locomotive becomes relatively higher under maximum than minimum boiler demands, while with electricity the cost per unit is at a uniform rate, whether working under extreme or light power demands. For example:

155 *Case 1.* A consolidation (2-8-0) type locomotive with 180,000 lb. on 57 in. drivers, 50 sq. ft. of grate surface, working under maximum conditions on a $1\frac{1}{2}$ per cent grade, would burn 150 lb. of coal per sq. ft. of grate surface per hour and evaporate from 12 to 15 lb. of water per sq. ft. of heating surface per hour. Under these conditions the cost per 1000 ton miles would figure out as follows:

$$\frac{F \times \text{price per ton} \times R \times 1000}{2000 \times \text{m.p.h.} \times E \times TF} = \text{Cost per 1,000 ton miles}$$

where F = coal per hour (150 lb. × 50 sq. ft. of grate surface).
R = resistance to be overcome [(grade per cent × 20) plus 6].
E = 80 per cent efficiency to cover losses such as cleaning fires, idle time while under steam, cylinder condensation, air pump consumption, etc.
TF = tractive force, in this case 180,000 lb. on drivers ÷ 4.5 = 40,000 lb.

Substituting these values, the formula becomes

$$\frac{7{,}500 \text{ lb.} \times \$2.85 \times 36 \times 1{,}000}{2{,}000 \times 10 \times 80\% \times 40{,}000} = \$1.20$$

If the same service is handled by electric locomotives the cost on a similar basis becomes

$$\frac{R \times (\text{watt-hr. per ton mile}) \times 1{,}000 \text{ tons} \times \text{price per kw. at the rail}}{1{,}000 \text{ watts}}$$

$$= \frac{36 \times 2 \times 1{,}000 \times \$0.01\frac{1}{4}}{1{,}000} = \$0.90$$

156 If locomotive coal is taken at \$1.70 per ton (the price in Eastern Pennsylvania for low grade soft coal), the cost for coal for locomotives under the foregoing conditions would be:

$$(a) \quad \text{Steam, } \frac{\$1.20 \times 1.70}{2.85} = \$0.716$$

(*b*) **Electric current reduced to 1c. per kw. hour at the rail:**

$$\frac{0.90 \times 1c.}{1\frac{1}{4}c} = \$0.72$$

157 *Case 2.* An express passenger locomotive of the Atlantic (4-4-2) type, with the following data: Cylinders 21 by 26 in., boiler pressure 200 lb. per sq. in., weight on drivers 102,000 lb., heating surface 2,821 sq. ft., grate surface 50 sq. ft., rate of combustion 150 lb. per sq. ft. of grate surface per hour, speed 70 miles per hour. Figuring as in Case 1

$$\frac{7{,}500 \times 2.85 \times 20 \times 1{,}000}{2{,}000 \times 70 \times 80\% \times 5.350} = \$0.71$$

Under electric conditions we have

$$\frac{20 \times 2 \times \$0.01\frac{1}{4} \times 1{,}000 \text{ tons}}{1{,}000 \text{ watts}} = \$0.50$$

or 28½ per cent less.

158 If coal is taken at $1.70 per ton, as in Case 1, the cost is reduced from $0.71 to $0.42, making the difference slightly in favor of steam.

159 These figures apply only to the conditions named, and average conditions on an undulating profile, when coasting is occasionally possible. With the benefits of momentum grades, also, the figures would be relatively less, but the electric locomotive would respond and benefit accordingly, so that the percentages would be approximately the same.

160 When steam locomotives are loaded to their capacity, as is generally the case where tonnage rating is practiced, the rate of combustion of 150 lb. of coal per square foot of grate surface per hour, will still hold good and remain constant, the tons hauled being the variable, responding to or being modified by the speed or physical conditions of the road.

SAVINGS CLAIMED FOR ELECTRIFICATION

161 In view of the foregoing the following extract from an article by Mr. C. L. De Muralt will be of interest. The figures are from the annual report of 1903 of the roads named.

COST OF OPERATING TRUNK LINES

	P. R. R.	N. Y. C.
Fuel for locomotives	$6,000,135	$4,635,877
Water " "	335,286	295,583
Other supplies for locomotives	382,548	334,673
Wages: Enginemen and roundhouse men	5,716,848	4,928,443
Other trainmen	4,442,127	2,991,335
Switchmen, flagmen and watchmen	3,900,427	2,511,552
Other expenses of conducting transportation	14,540,542	11,607,538
Repairs to locomotives	4,412,983	3,608,972
" other equipment	10,674,726	5,661,992
" roadbed	8,542,935	6,145,341
" structures	4,122,018	2,454,691
General expenses	1,858,319	1,786,494
	$64,928,894	$46,962,491

162 Mr. De Muralt then applies the figures found during the course of his investigation, which would lead to the following reductions if electricity was adopted as a motive power.

	P. R. R.	N. Y. C.
Fuel 10 per cent	$600,013	$463,388
Water saved entirely	335,286	295,583
Other supplies 50 per cent.	191,274	167,336
Wages, enginemen, etc., 25 per cent	1,429,212	1,207,361
Repairs to locomotives	2,206,492	1,804,486
Total amount saved	$4,762,277	$3,938,154

163 The saving in water alone capitalized at 5 per cent equals $6,750,000 for the former and nearly $6,000,000 for the latter road. As large as these alleged savings are, yet they would not amount to more than 2½ to 3 per cent on the necessary increase in capital to electrify the roads on which the foregoing savings apply.

164 While the first cost for power stations and electric equipment represents a large outlay, yet such items as the cost for repairs of locomotives and shops, expensive hostlering at terminals, coaling and water stations, and the incidental labor charge and repairs thereto will, in the aggregate, be materially reduced. The comparative saving in repairs will be indicated by the following figures:

Repairs	Steam	Electric
Boiler	20%	0%
Running gear	20%	20%
Machinery	30%	15%
Lagging and painting	12%	5%
Smoke box	5%	0
Tender	13%	0
	100%	40%

OTHER COMPARISONS BETWEEN STEAM AND ELECTRIC LOCOMOTIVES

165 It is further claimed that, with electric operation, greater mileage is possible with the electric locomotive and that fewer units are necessary to perform the same service. Great stress is laid on the fact that the ordinary freight locomotive makes only 3,000 miles per month, or 100 miles per day, against which is put forward

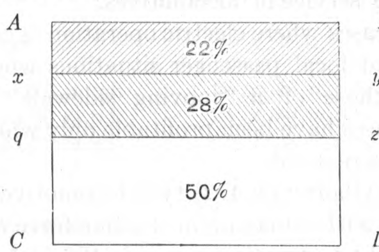


FIG. 17 DIAGRAM SHOWING DIVISIONS OF LOCOMOTIVE WORKING DAY

the ability of the electric locomotive to perform practically continuous service, suggesting the propriety of comparing electric and steam operation on the basis of ton miles per annum each is able to make and also the relative weight on driving wheels and not their total weight.

166 The operating efficiency of a steam locomotive in freight service is so low, averaging about 3,000 miles per month, that it is generally thought due to limitations, *per se*, in the locomotive, whereas it is mainly due to operating and traffic conditions, which limitations would apply with equal force to the electric locomotives, so that barring some increase in speed, the electric locomotive can make no greater mileage than its steam competitor in equivalent service, consequently its splendid ability to perform almost continuous service cannot be realized in practice for reasons aforesaid.

167 Let the rectangle *ABCD* represent a day of 24 hours; the shaded area *ABxy* that portion of the time for which the mechanical department is responsible = 22 per cent; the area *xyqz*, the average

time the locomotive is performing useful work = 28 per cent—i. e., actually pulling trains, 3000 miles per month, 100 miles per day; while the portion of the diagram bounded by $qzCD$, is the period or balance of the time that the locomotive is under steam, with crew, and ready to go, and represents the time at terminal yards, side tracks and awaiting orders, etc. = 50 per cent.

168 It is just here that our electrical friends make the great mistake of claiming "greater capacity" for the electric locomotive over its steam equivalent. It is conceded that under electric conditions the area $ABxy$ may be reduced as much as one-half and perhaps, owing to greater speed, the area $xyqz$ may be increased, but the "lost motion" period due to traffic and operating causes will be relatively the same for both. The percentages are from an actual three months' test on a trunk line reported in 1904 in the proceedings of the American Railway Master Mechanics' Association by the committee on time service of locomotives.

169 The only cases where electric operation is commercially justified is in congested local passenger situations where the conditions closely approach those of a "moving sidewalk" and the records show that these cases have been profitable only when a large increase in business has been realized.

170 A modern Atlantic (4–4–2) type locomotive weighs, including tender, 321,620 lb. with a maximum tractive force of 23,500 lb. The ratio of total weight to tractive power is 133 to 1. The New York Central electric locomotive, with a total weight of 192,000 lb. and a tractive effort of 27,500 lb. has a ratio of 7 to 1. The comparison is still more favorable for electric freight locomotives where the entire weight is on the driving wheels.

POWER STATION CAPACITY

171 The impression is quite prevalent that if 100 steam locomotives are required to operate a certain division, a power station capacity equivalent to 100 locomotives would be necessary, if operated electrically, whereas the generator capacity, barring the installation of spare units, would be of such size as to meet the average load. This average can be determined by laying down a train sheet, from which the load at any hour in the day can be seen and the peaks located.

172 For ordinary computations the number of trains to provide for is, approximately:

$$\frac{\text{total train miles per hour}}{\text{mean speed}}$$

173 This formula is the result of cancellation from the following:

(*a*) h. p. days ÷ Aggregate h. p.

That is:

$$(b)\ \frac{5{,}280 \times (\text{distance miles}) \times (\text{no. trains}) \times (\text{tons}) \times R}{47{,}520{,}000 \text{ ft. lb. in 1 day}}$$

$$\div \frac{\text{tons} \times R \times \text{m.p.h.}}{375}$$

R = resistance due to gravity, + resistance due to speed, + curve resistance. Transposing and cancelling:

$$(c)\ \frac{\text{distance miles} \times \text{no. trains}}{24 \times \text{m.p.h.}}$$

For illustration take a typical case: Distance 183 miles.

LOAD		AVERAGE SPEED	
37 freight trains	at 15 m.p.h.	37 × 15 m.p.h. =	555
22 expresses	at 50 m.p.h.	22 × 50 m.p.h. =	1,100
21 locals	at 30 m.p.h.	21 × 30 m.p.h. =	630
80 trains total.		80	2,285

2285 ÷ 80 = 28 average m.p.h.

$$\frac{80 \text{ trains} \times 183 \text{ miles}}{24 \text{ hr.} \times 28 \text{ m.p.h.}} = 22 \text{ trains}$$

174 For more accurate work a train sheet should be made either with miles as ordinates and time as abscissae, or one with trains as ordinates on a time (abscissa) base.

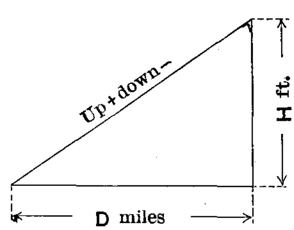
175 Relative to R (*i.e.*, resistance for gravity), divide the profile into sections, one for each change in grade, plus or minus as the case may be:

$$\frac{H}{D \times 52.8} = \text{per cent grade}$$

Each 1% grade = 20 lb. = R

R for curves 0.56 lb. per deg.

$$R \text{ for level sections } = 2 + \frac{\text{m.p.h.}}{4}$$



176 Consider the example of a road or division 100 miles long on which a given train requires 2,000 h.p. to keep it in motion. If 20

cars take a maximum of 100 h.p. each, the electrical conductors and distributing apparatus will never be required to deliver more than 100 h.p. at any one point. If on the other hand, the entire traffic of the line must be concentrated in a single train, the electrical conductors and distributing apparatus must deliver the full 2,000 h.p. at each and every point. In other words, with the concentrated load, the capacity of the distributing apparatus at each and every point must be 20 times as great as the capacity when 20 cars are used to give the same total load. Electric traction has proved its superiority for distributing loads, but concentrated loads are still handled almost exclusively by steam locomotives.

SOME ADVANTAGES OF ELECTRIC LOCOMOTIVES

177 In the annual report of the P. R. R. (1903) the president states: "That the congested condition of your system has brought about a large increase in the ton mile cost, which for 1903 was 25 per cent greater than for 1899. In order to prevent the increase in ton mile cost, it is necessary to move freight trains faster in places where traffic is dense, and for such purposes the electric locomotive is most efficient."

178 With steam locomotives the most economical average speed, for freight service, is 12 to 15 miles per hour, where there is ample track space for the free movement of trains. With a dense traffic this free movement can only be obtained by a higher speed and if the large train tonnage be maintained, more horsepower is required of the engine and boiler. It is difficult to increase the size of steam freight locomotives without resorting to the Mallet compound articulated type, and here we have the equivalent of two locomotives in one machine.

179 With the electric locomotive it is possible to develop a much greater horsepower and a large percentage of overload at the time when needed and do it more economically than with steam. The New York Central electric locomotive has a maximum peak horsepower of 3,000, which is 25 per cent above normal. This maximum is about double the power which can be obtained from the New York Central standard Atlantic (4–4–2) type locomotive. Similar proportions can be obtained for electric freight locomotives and their size and power are not limited by boiler capacity. If the steam locomotive is capable of developing 30,000 T. F. at the drawbar at 12 m.p.h. or

$$\frac{30{,}000 \times 12 \text{ m.p.h.}}{375} = 960 \text{ h.p.}$$

and it is required to increase the speed of the train to 20 m.p.h. and maintain the same tonnage, then 1,600 h.p. will be required, which means the employment of a much larger locomotive or double heading.

180 The advantage of the overload capacity on short mountain grades or for strategic peaks is one of the strong points in favor of the electric machine and would make electric operation applicable to special cases rather than a universal substitute, in the broad light of commercial considerations.

GENERAL CONCLUSIONS

181 Our conclusion, from this survey of the situation, is that the rapid development of suburban passenger traction by electricity will require large power houses at large cities and these can gradually be made sufficient for working the line on further stretches in each direction, handling congested terminals, or used where commercially practicable, until it may be desirable to electrify the entire division.

182 Electric operation as compared with steam shows to greatest advantage in urban and suburban passenger service. Here, if multiple unit trains are employed, so that a considerable fraction of the total weight is carried on the driving wheels, thus permitting a high rate of acceleration to be used, a schedule speed quite impracticable in steam operation can be maintained. Moreover, a more frequent service can be given without a proportional increase in expense, whilst in times of light traffic small trains can be run, the energy consumption per train in such service being almost in proportion to the number of coaches. The law of induced travel, however, applies to urban and suburban passenger service, but does not hold for trunk lines and especially freight service.

TO DETERMINE WHETHER IMPROVEMENTS ARE JUSTIFIABLE

183 Under trunk line conditions the only thing that interests railway managers is the traffic available at the present, relatively speaking; the future is too indefinite to be capitalized to any great degree in advance. It is more in the line of insurance companies to "capitalize expectations."

184 In grade revision the authorization for expenditure is based on the saving in train miles capitalized. The following is a concrete case from a Western road, or rather the summation of the engineer's

report as to just what the proposed rearrangement would amount to. The rate of 50 cents per train mile is to cover those items of cost directly affected by the change.

$$\left[\begin{array}{l}\text{No. of}\\ \text{trains per}\\ \text{day—7}\end{array}\right] \times \left[1 - \frac{1{,}350 \text{ tons present conditions}}{1{,}600 \text{ tons proposed}}\right]$$

$$\times \left[\begin{array}{c}\text{Div. of}\\ 225\\ \text{Miles}\end{array}\right] \times 50\text{c.} \times \left[\begin{array}{c}365\\ \text{days}\end{array}\right] = \$45{,}990$$

185 Under the circumstances it will be seen that the value of 1 per cent reduction in train mileage amounts to $1.95 per mile per train per annum. The total amount capitalized at 5 per cent equals $919,800. In some such manner the steam railroad manager arranges the proposition of the electric scheme and decides accordingly.

SOME EXAMPLES

186 In a paper before the American Society of Civil Engineers by W. J. Wilgus, some interesting data concerning New York Central operation were given:

Cost of coal per 2,000 lb. anthracite steam locomotive, terminal service.	$4.46
" " bituminous coal, road service	3.12
" " " " power station	2.72
Water per 1,000 gal. :—	
Power station	13.5 cts.
Road service	5 "

187 The cost of current, when power station designed load is attained, is 2.6 cents per kilowatt hour delivered at contact shoes. This includes all operating and maintenance costs, interest on the electrical investment required to produce and deliver current, depreciation, taxes, insurance and transmission losses. The following table summarizes the data:

Items	Operating Costs	Fixed Charges	Total
Power station	0.58 cts.	0.44 cts.	1.02 cts.
Transmission losses	0.19 cts	0.15 cts.	0.34 cts.
Distribution systems			
Sub-stations	0.32 cts.	0.92 cts.	1.24 cts.
Totals	1.09 cts.	1.51 cts.	2.60 cts.

188 In a discussion by G. R. Henderson[1] are given road service costs per 1,000 car ton miles:

	Steam	Electric
Supplies	$2.03	$1.37
Wages	0.28	0.31
Interest, depreciation, and repairs to locomotive	0.46	0.34
	$2.77	$2.02

189 The item electric supplies is composed of operating expenses and fixed charges and may be analyzed thus:

53.3 kw-hr. at $0.0109, $0.58 operation
52.3 kw-hr. " 0.0151, 0.79 fixed charges
52.3 kw-hr. " 0.026, 1.37

$$\left[\text{Fixed charges} = \left(\frac{0.79}{1.37}\right) = 57 \text{ per cent of operating expenses}\right]$$

The brackets are ours. The difference in cost between steam and electric traction in road service is $2.77 − $2.02 = $0.75 per 1,000 car ton miles.

190 The fixed charges on the power plant and the transmission system are $0.79 per 1,000 car ton miles, or about the same as the saving, so that if the train movement were but one-half the assumed amount (averaging 6,000 h.p. at the rails, or 6,000 kw. at the station) the cost for electric service would be slightly higher than for steam, or $2.81 as against $2.77 per 1,000 car ton miles.

191 The Manhattan Elevated, with about 38 miles of road, was electrified at an expense of $17,000,000. The operating ratio, under electric conditions, has been reduced from 61 to 46 per cent of gross receipts. The net result after taking care of the increased capital, etc., shows 15 per cent profit, but it is a significant fact that the increase in business was 46 per cent (carrying about 250,000,000 people per annum, 690,000 per day average, or 28,800 per hour).

192 There has just been reported the four years' electric operating results of the Mersey tunnel road connecting Liverpool and Birkenhead. The net profit, allowing interest, etc., on the increased capital due to electrification, amounted to 15 per cent, but it took an increase in traffic of 55 per cent to make this operating result possible. Ton miles increased from 43 to 67 million, or 55 per cent. Total expenses, which include operating expenses and interest on electric capital (but not depreciation) equal $0.586 per ton mile. Interest equals $0.106 per ton mile, or 22 per cent of operating expenses.

193 President Harahan of the Illinois Central reports the results

[1]Trans. A.S.C.E., vol. 61, p. 102.

of the investigation that has been made relative to the proposed electrification in the following words:

194 "Our suburban traffic is the only service which would in any degree be adapted to electric operation, but even in this particular service it can be readily shown to be unjustifiable at the present time. I submit below a statement of the results which are estimated to accrue if the entire suburban service were electrified, compared with the present steam operation:

"Results of Operation of Suburban Business at Chicago for Fiscal Year ending June 30, 1909:

Gross earnings		$1,056,446
Operating expenses (82.9%) plus taxes		946,734
Net revenue		$109,712
"Estimated Results Under Electrification:		
Gross earnings		$1,056,446
Operating expenses (66%)	$697,254	
Taxes	74,427	
		$771,681
Net revenue (electric operation)		$284,765
Net revenue (steam operation)		109,712
Increase		$175,053
Estimated cost of electrification		$8,000,000
Interest and depreciation 10%		$800,000
Saving in operation under electrification		175,053
Deficit		$624,947

195 "Our suburban traffic is not sufficiently dense to warrant the expense necessary to electrify these lines, and it is evident from the foregoing figures that even under electrification there would not be an increase in traffic sufficiently large to offset the annual loss from operation. It simply proves that under present conditions of cost of electrification of steam railways, where it means a replacement of a plant already installed, and serving the purpose, it is not justifiable to electrify either in whole or in part your Chicago terminals at this time."

196 The suburban district of the Illinois Central covers about 50 miles of road and carries in round numbers 15,000,000 suburban possengers per annum, or an average of 41,150 per day, or 1,700 per haur. An increase of 100 per cent in earnings would not enable the road to break even.

197 The Railway Age Gazette, in commenting editorially on Mr. Harahan's statement, says:

198 "It may be accepted as conclusively demonstrated that the New York Central and the New Haven roads are moving trains by electricity more economically than they moved them by steam in their suburban district. To enable this to be brought about, however, extremely heavy capital costs had to be assumed and the charges on these capital costs make the entire operating cost, including overhead charge, far higher than it used to be in the days of steam operation.

199 "For example, a standard express train of eight cars on the New Haven road pulls out of Grand Central station headed by two half-unit electric locomotives, each of which cost very nearly $40,000. The capital cost of the motive power of this train is in excess of $75,000 [the interest and depreciation amounting to $20 per day]—the brackets are ours. The cost of motive power at the head of a similar New York Central passenger train operated by electricity is about one-half this sum. Moreover, it will be recalled that Mr. Wilgus estimated that the direct costs of electrical equipment represented only one-fourth of the total charges attendant upon electricity. The cost of making everything ready and safe for this kind of operation is far greater than the highest estimates are apt to contemplate."

200 From a report of the Electrical Commission of the State of Massachusetts the following extracts are taken (letter of C. S. Mellen, president of the New Haven road):

201 "We believe we are warranted in saying that our electric installation is a success from the standpoint of handling the business in question efficiently and with reasonable satisfaction, and we believe we have arrived at the point where we can truthfully say that the interruptions to our service are no greater, nor more frequent than was the case when steam was in use. But we are not prepared to state that there is any economy in the substitution of electrical traction for steam; on the contrary, we believe the expense is very much greater."

202 The Boston & Albany Railroad Company reports the result of their study and estimates the requirements as follows: A power station of 6000 kw. will be necessary, with storage batteries to handle the peak load. The total cost of the installation is estimated at $4,000,000, and the interest, taxes, and depreciation at 9 per cent, or about $400,000 per annum. A stock argument for electric operation is the saving to be made in operating expenses, but concerning this the following statement is made:

203 "Some slight economies would accrue in the transportation

expenses under this operation, which would be substantially absorbed by the additional expenses to be incurred for the maintenence of the additional apparatus installed, and the net economies would be so small as to be inappreciable in the consideration."

204 Another stock argument of the advocates of electric locomotives is the growth of traffic which is supposed to result from electric operation. This argument is met as follows in the report:

205 "Considering now the possibilities of increasing the traffic, the statistics of the B. & A. R. R. show substantially the following numbers of passengers handled in the above territory per annum:

1891	4,552,918	1899	3,897,364
1894	4,799,578	1907	4,435,841

206 "The absence of any material increase in traffic is probably due to the fact that the circuit is occupied as a high class residential district not susceptible of rapid subdivision of property, and more particularly to the fact that suburban lines are being rapidly extended into all such outlying districts and afford a more advantageous means of collecting and distributing local travel through the commercial and residential districts than could possibly be afforded by a railroad constructed and operated upon private right of way and devoted largely to long haul operations."

EXAMPLE TO ILLUSTRATE A CONCRETE CASE

207 The following illustration representing a concrete case is selected because of its elementary character, more especially as the case is so simple that all the variables affecting the comparison are eliminated and the amount of coal to perform the operation is directly known:

Conditions: trailing load 1,600 tons; average grade, 1.3 per cent; distance, 8 miles; speed, 15 miles per hr. for electric and 14 miles per hr. for steam locomotive.

(*a*) Electric

1,600 net tons
190 locomotives (2) tons
———
1,790 gross tons

$$R = \begin{cases} 1.3\% \text{ grade} \times 20 = 26 \text{ lb.} \\ 5^\circ \text{ curves} \quad 3 \text{ lb.} \\ \text{Level} \quad 6 \text{ lb.} \end{cases}$$

$$\frac{\text{gross tons} \times R \times \text{distance}}{500} = \text{kw-hr. at the rail}$$

Substituting values:

$$\frac{1{,}790 \times 35 \times 8}{500} = 1{,}000 \text{ kw-hr. (at rail)}$$

Equivalent kilowatt load at power house =

$$\frac{\text{tons} \times R \times \text{ m.p.h.}}{500 \times \text{efficiency } \%}$$

Where the efficiency between the rail and generators equals 65%, substituting as before:

$$\frac{1{,}790 \times 35 \times 15}{500 \times 65\%} = 2{,}900 \text{ kw.}$$

For this particular case current can be purchased from an adjacent power house at the very low rate of one cent per kw-hr. at the rail.

At this rate the power cost per trip will be 1,000 kw. at one cent = $10

(*b*) Under steam conditions we have the same as before, 1,600 net tons + weight of two locomotives, 300, or 1,900 gross tons.

The coal consumption for this particular run is 6,000 lb.

The price per ton to equal the electric cost for power, is:

$$\frac{6{,}000 \text{ lb.} \times \text{price per ton}}{2{,}000} = \$10$$

Transposing:

$$\frac{2{,}000 \times 10}{6{,}000} = \$3.33$$

But as coal for this particular case costs the road $1.70 per ton, the relative cost, coal against power, is

$$\frac{6{,}000 \times \$1.70}{2{,}000} = \$5.10$$

There is a difference in ton mile hours, in favor of the electric locomotive, due to speed and reduced gross tonnage, as follows:

$$a \quad \text{Electric} \quad \frac{1{,}790 \times 8 \times 8}{15} = 7{,}640 \text{ gross ton mile hours}$$

$$b \quad \text{Steam} \quad \frac{1{,}900 \times 8 \times 8}{14} = 8{,}690 \text{ gross ton mile hours}$$

To make the comparison correct the coal consumption of the steam locomotive should be proportioned on the ton mile hours produced, and the cost of coal then becomes:

$$\frac{\$5.10 \times 8{,}690}{7{,}640} = \$5.80$$

Adding to the foregoing the other operating costs, the relative expense becomes

(*a*) *Electric*. Power $10.00

Lubrication, supplies, repairs, crew at $0.1158 per 1,000 ton miles, or

$$\frac{0.1158 \times 1{,}790 \times 8}{1{,}000} = \text{................} \quad 1.66$$

Interest and depreciation, taxes, insurance, etc., at 10%.. 1.46

$13.12

(*b*) *Steam.* Coal as above $5.80

Lubrication, supplies, water, repairs, enginemen at $0.25 per 1,000 ton miles,

$$\frac{\$0.25 \times 1{,}900 \times 8 \text{ miles}}{1{,}000} = \ldots\ldots\ldots\ldots \quad 3.80$$

Interest and depreciation at 10% (2 locomotives)

$$\frac{\$34{,}000 \times 10\% \times 8}{365 \times 24 \times 14} = \ldots\ldots\ldots\ldots \quad 0.22$$

$9.82

Cost per trip in favor of steam, $3.30, or 25% less

208 The idea is all too prevalent with the public, and even with some of the bodies that have been given legal power of supervision over railway companies, that any expenditure which can be forced upon the railway companies is just so much gain for the public. Never was there a more absolute fallacy. In the long run, the cost of every bit of railway improvement must be paid for by those who buy tickets and ship freight. Economy in the administration of our railways is just as important in the interest of the general public as if the railways were actually under government ownership.