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OF THE
ELECTRIC LOCOMOTIVE
FOR THE
STEAM LOCOMOTIVE

BY

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and
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A paper presented at the 214th meeting of the American Institute of Electrical Engineers,
January 25, 1907

WITH DISCUSSION

Reprinted from Volume XXVI of the Transactions

PUBLISHED BY
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
33 WEST THIRTY-NINTH STREET
NEW YORK

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ON THE SUBSTITUTION OF THE ELECTRIC MOTOR FOR THE STEAM LOCOMOTIVE.

BY LEWIS B. STILLWELL AND HENRY ST. CLAIR PUTNAM.

The purpose of this paper is fourfold: 1, to record certain facts relative to heavy electric traction which have been established by experience; 2, to present calculations of relative costs of steam and electric traction in railway service based upon these facts; 3, to point out the transcendent importance of standardizing electric railway traction equipment as rapidly as may be consistent with progress; and 4, to raise the question whether a frequency of 25 cycles per second or 15 cycles per second should be adopted in railway operation by alternating-current motors.

Few subjects which are to-day engaging the attention of the engineering world are comparable either in scientific interest or in practical importance to the substitution of the electric motor for the steam locomotive engine. Three-phase and single-phase alternating-current railway motors are now developed to a point where they fairly challenge the steam locomotive, even in long-haul freight service, in which class of work the direct-current motor hitherto has found itself unable to compete with success. The direct-current motor has demonstrated impressively, and upon a large scale, its superiority to the steam locomotive, not only in operating single cars and short trains on lines of moderate length, but also in frequent and heavy passenger service in which the length of train is limited only by the length of station platform, while the motive power equipment far exceeds in power developed the limits hitherto established in steam passenger service.

On the Valtellina line and through the Simplon tunnel 70-ton electric locomotives with three-phase motor equipment, capable of developing a draw-bar pull of 28,000 lb., have displaced the steam locomotive, with results showing both marked improvement in service and substantial economy in operating costs. In the New York Subway, eight-car trains weighing 320 tons are in operation, equipped with motors developing during acceleration a tractive effort equivalent to a draw-bar pull of 55,000 lb.

The heaviest passenger locomotive used on the Erie system in 1905, weighs, exclusive of tender, 206,000 lb., of which 55.8%, or 115,000 lb., is effective on drivers. Assuming the adhesion to be 20%, such a locomotive exerts a draw-bar pull of 23,000 lb. The motors of the eight-car electric train of the New York Subway, therefore, exert a tractive effort equivalent to more than twice the draw-bar pull of this locomotive.

Managers and engineers of railways using steam are considering the possibilities of electricity. Naturally, the problem usually presents itself in reference to particular cases in which special conditions emphasize the advantages of electric traction; but a point has been reached in the development of electric railway equipment where it is evident that no absolute and permanent limits beyond which the motor may not go can be fixed; and it is not unreasonable to consider the possibilities of the electric motor not only in passenger service but also in freight service, not only in the operation of railway terminals, but also for the operation of railway divisions and even for trunk lines.

At the present time, what is needed is not prophecy but facts, and particularly facts demonstrated by experience. A study of the relative advantages of steam and electric traction should rest as firmly as possible upon results attained in practical operation. Facts thus established and available to date are insufficient to justify conclusions which in detail may not have to be modified, but it is believed that they are adequate to permit comparative studies leading to deductions, which, as a whole, may be relied upon.

The answer to the question: " Will it pay to electrify? " involves consideration of both relative earnings and relative cost of operation; therefore, before discussing the comparative expenses involved, it is pertinent to refer briefly, even at the risk of repeating what has been said in papers hitherto presented by others, to the more important factors which co-operate in securing for electric traction an increase in earning power.

PASSENGER SERVICE FACTORS CONTRIBUTING TO INCREASED EARNING POWER.

The more important considerations which affect gross earnings are:

1. Frequency of service.
2. Speed.
3. General comfort of passengers.
4. Safety.
5. Reliability of service.
6. Increased capacity of line.
7. Frequency of stops.
8. Convenient establishment of feeder lines.

1. *Frequency of Service.* The motor-driven, interurban car operating upon scores of lines in competition with steam railway service has convincingly demonstrated its ability, not only to attract business from competing steam lines but also to create new business. In almost every case where such competition has been encountered by the steam railway, a large part, if not practically all of its local passenger traffic has been lost. In comparing results attained by the competing systems in such cases, it is impossible, of course, to state in terms of precision how far frequency of service is responsible for the remarkable results observed, since to these results a number of other causes also contribute. But without attempting to differentiate between these various factors, it is sufficient here to say that of the several causes contributing to the marked success of lines using electricity, the operation of train units or of single cars upon close headway is recognized to be especially attractive.

The advantages resulting from frequency of service become relatively less as the length of run is increased. It is recognized, however, that the operation of trains under close headway generally increases traffic, even where the haul is of considerable length, as shown by the experience of the Philadelphia & Reading Railroad in operating its fast trains upon one-hour headway between New York and Philadelphia.

2. *Speed:* The possibilities of operating by electricity at speeds exceeding the maximum which can be obtained safely in steam operation, owing to the elimination of unbalanced reciprocating

parts of the locomotive, is well-known. It was strikingly illustrated in the Berlin-Zossen trials by the attainment of a speed exceeding 130 miles an hour. These tests demonstrated the ability of electric equipment to operate at a sustained speed more than twice as great as that of our fastest express trains on runs of any considerable length, and exceeding by about 50% the maximum which can be attained even for a short distance by the steam locomotive with a reasonable degree of safety.

Even at speeds at which steam locomotives may be operated without great danger of leaving the track, as a result of the effect of unbalanced reciprocating parts, electric engines are far better able to maintain speed while drawing heavy trains. At speeds of 80 or 90 miles an hour, for example, it is extremely difficult to operate with satisfactory results two steam locomotives at the head of the train; while multiple-unit control places any necessary number of locomotive units absolutely and instantly responsive to the will and touch of a single operator. At high speeds, also, the economy of the steam locomotive falls off rapidly while that of its competitor remains practically constant.

The increase in average speed resulting from the relatively high acceleration obtainable in the use of multiple-unit electric equipment in service where stations are very close together; *e.g.*, elevated and subway lines in cities, and in suburban service in the vicinity of large cities, has been discussed frequently from the theoretical standpoint and is well understood.

3. *General Comfort of Passengers:* The great advantages of electric traction in respect to comfort of passengers are well-known. Cleanliness and improved ventilation made possible by the elimination of smoke and cinders; lighting practically without heat and at low cost by a system which makes it easy to place lights in any desired location, and heating apparatus effectively and conveniently controlled, are factors of very great importance in building up passenger business under conditions of competition. In operating through tunnels, ventilated with difficulty, the electric motor, in eliminating smoke and the gases of combustion, possesses an advantage which is frequently controlling.

4. *Safety:* So much has been said and printed in the daily press regarding the alleged dangers of electric traction, that it is well to place on record here a statement of the considera-

tions which inevitably lead to the conclusion that electric traction, if the equipment be properly designed and installed, is essentially and materially safer, so far as the traveling public is concerned, than steam traction. The more important of these considerations are:

a. The fact that in case of a rear-end collision, which is perhaps the most frequent form of accident experienced in the operation of our railway systems, the energy which propels the electric train can be shut off generally with great promptness. On the other hand, the steam locomotive carrying in its fire-box from 1500 to 2000 lb. of coal heated to incandescence, almost invariably sets fire to any broken cars, or other combustible material with which it comes in contact. Where the electric supply to trains is obtained at low potential from a third rail, the risk of short circuit, which may result in fire if the cars be not fireproof, is greater than it is in the case of overhead construction, even when the voltage employed in the latter case is very high. In fact, in the latter case it may be said that risk from the physiological effects of the current or from fire resulting from short circuit, is practically eliminated, except perhaps in tunnels of very limited clearance.

b. The elimination of the boiler carrying steam at high pressure, also means the removal of an element of risk which in many railroad accidents has destroyed life.

c. The absence of smoke in tunnels, and consequent ability to see signals clearly at all times, constitutes an advantage ot the utmost importance for electric operation.

d. Cars drawn by steam locomotives must be heated either by steam from the locomotives, or by some form of stove carried on the individual cars. In the former case, steam from broken steam pipes becomes a serious source of danger in case of accident; in the latter the hot coals from the stove, even in the improved modern types which have greatly reduced the risk formerly encountered, are a source of danger. The substitution of the electric heater affords opportunity not only for ideal control of temperature of the cars but almost absolutely eliminates risk of fire.

e. The elimination of the gas tank and the oil lamp used for lighting in steam traction, and the substitution of electric lighting, also implies a material gain in safety.

f. The danger of derailment in the case of the electric locomotive is far less than in case of the steam locomotive, by reason of the elimination of unbalanced reciprocating parts which tend to lift the steam locomotive from the tracks. The hammer-blow also, in the case of the steam locomotive, is responsible not infrequently in cold weather for broken rails, as a direct result of which many serious accidents have occurred.

g. The electrification of railways where high-speed passenger traffic is involved, affords opportunity for improved methods of protecting trains by signal systems, automatic or other.

h. The ability to cut off power at will from a given section and therefore from trains operating upon that section under certain conditions, which arise not infrequently in railway service, may be availed of to prevent accidents. In steam railway service, when an operator at a tower having allowed a train to pass learns too late that another train is approaching in the opposite direction, he is powerless to avert the impending collision. Where the motive power of these trains, however, is transmitted by electricity, the power supplied to the section might be cut off and probably in time to prevent the catastrophe.

As against the considerations above referred to, all of which tend to make electric operation safer than operation by steam locomotive, the addition to the permanent way equipment of an electric conductor conveying power to trains imposes in the former case a material risk not involved in the latter. If the power be supplied through a third rail, a guard should be used whenever possible to prevent accidental contact with the rail by employes or by others walking upon or crossing the track. Several effective forms of guard are available, of which at least one has been in service upon a convincing scale for five years.

5. *Reliability of Train Service:* Interesting evidence in respect to the relative reliability of steam locomotives, and of electric motors carried upon cars and controlled by the multiple-unit system of train-control, is derived from the official records of the transportation department of the Manhattan Division of the Interborough Rapid Transit system of New York. Upon the elevated lines, steam locomotives were used from the inauguration of the first constituent line of the ultimate system in 1872 until 1902, during which year and a part of the following year, electric equipment was gradually substituted. The locomotives were operated under exceptionally favorable conditions, were not overloaded, were of simple construction, and admirably maintained. The electric equipment that succeeded them is operating trains which average

5.3 cars as against 3.8 cars in the days of steam operation. The average speed is materially higher. The tractive effort during acceleration of a six-car train is 30,000 lb. as against a maximum draw-bar pull of approximately 7,000 lb. exerted by the steam locomotive.

Accurate record is kept of the duration of every delay in the operation of the trains. The results for the months November 1900 to March 1901, when steam was used, and the corresponding months of the years 1905-6 under conditions of electric operation, illustrate in a striking manner the marked gain in reliability of service which has resulted from the adoption of electricity. For the five months of steam operation the aggregate car-mileage was 18,527,773 miles, and the aggregate delay 8258 train minutes. The car-mileage per train-minute delay was 2243.

For the corresponding period of electric operation, 5 years later, the car-mileage was 25,482,081, the aggregate train-minutes' delay 5970 and the car-mileage per train-minute delay was 4268.

It will be noted that the months involved in the above comparison are those in which the difficulties of operation, owing to weather conditions and number of passengers transported are at a maximum. Snow and sleet are among the greatest difficulties to be overcome in the operation of a third-rail system, when, as in the case of the Manhattan, the third rail cannot be effectively protected by reason of limitations in space available on the stucture. In view of these difficulties and of the increase in density of traffic, the results obtained are remarkable.

6. *Increased Capacity of Line.* Electric traction as compared with steam traction enables us to develop much greater sustained tractive efforts with given weight on drivers, by reason of more uniform rotative effort. Even where electric locomotives are used, it also eliminates dead weight by abolishing the tender and facilitating construction under which practically the entire weight of the locomotive is carried upon the drivers. Where the locomotive is dispensed with, and the motors mounted directly upon trucks of cars constituting the train, the best results are obtained, the proportion of weight upon wheels driven by motive power being greater than is otherwise practicable. This increase in weight available for adhesion, in conjunction with the characteristics of the electric motor, makes it possible to attain in electric service rates of accelera-

tion altogether impracticable in steam service; consequently trains in passenger service where short headway is desirable can follow each other at shorter intervals than is feasible where steam motive power equipment is employed.

In the operation of freight trains, if it should ever become practicable to distribute electric locomotives throughout the length of the train and operate them by multiple-unit control, trains of length far beyond present limits could be operated. At present, the length of a freight train is limited by the strength of the draft-gear, and steam locomotives cannot advantageously be distributed at intervals throughout a very long train, as no means is available for controlling their effort simultaneously and satisfactorily.

Obviously, a system permitting distribution of the motive power at convenient intervals throughout the train, and simultaneously controlled by the hand of a single engineman, presents possibilities of increasing track capacity which under conditions now existing on many through lines should be of great value.

7. *Frequency of Stops:* The interurban electric line competing with the steam railroad for traffic between two cities possesses great advantage in the collection and distribution of passengers, from the ability of its cars to stop at any street intersection or other convenient point, instead of receiving and discharging passengers at a single railway station in each town. These frequent stops, however, operate to reduce speed materially, and but for the ability of the electric equipment to accelerate rapidly the limitation would be very serious. As speed between terminals is increased, the tendency to reduce the number of stops made to take on or let off passengers is noticeable in the development of many interurban lines.

8. *Convenient Establishment of Feeder Lines:* Frequency of stops for convenient collection and distribution of passengers, and high speed between terminals, being considerations which are essentially opposed, the advantages of a four-track system permitting operation of local or collecting train units on two tracks, and express trains on the other two tracks, are obvious. The great expense of such a system, however, can be borne only where traffic is very heavy.

A natural development which during the last five years has been very rapid, is found in the use of comparatively short electric trolley lines in connection with steam express service for long-distance runs. This method of utilizing the advantages of local electric lines by the companies operating trunk line systems is eminently wise, and in general should be highly advantageous to the properties concerned while increasing materially the facilities offered to the public. It may be pointed out, however, that were the trunk line systems to utilize electricity for through traffic, the extension and systematic improvement of local feeders would be facilitated for a number of reasons, notably:

1. The fact that power developed in large amount, as for the operation of heavy through traffic, is produced at low cost per unit, and would be available at all points along the line for the operation of cars on local feeder lines.

2. The convenient possibility of attaching cars or short trains arriving on local lines to through trains at points of junction. The multiple-unit system of car equipment lends itself admirably to this method of operation.

ILLUSTRATIONS OF PASSENGER BUSINESS DEVELOPED BY INTERURBAN ELECTRIC LINES.

In a very comprehensive paper presented by Mr. J. G. White before the International Engineering Congress at St. Louis in 1904, the following striking illustrations of the advantages of frequent service are given:

"*Cleveland-Oberlin Line.* These cities are 34 miles apart. The competitors for passenger traffic between these cities and intermediate points are the Lake Shore & Michigan Southern Railroad (steam) and the Cleveland, Elyria & Western (electric). In 1895 the total number of passengers carried by the steam railway between these cities and intermediate points was 203,014. This total decreased gradually after the competing electric line was opened to a minimum in 1899 of 71,755, from which it gradually recovered in 1902 to 91,761, but during this same year the electric road carried a total of about 3,000,000.

"*Cleveland-Painesville Line.* These cities are 39 miles apart. The competitors for passenger traffic are the Lake Shore (steam) and the Cleveland-Painesville & Eastern Railway (electric). In 1895 the steam road carried between the terminals and intermediate points 199,292 passengers, but in 1902 it carried only 28,708 passengers, while the electric system carried 1,537,754 passengers.

"*Cleveland-Lorain Line.* These cities are 26 miles apart.

Competitors are the New York, Chicago & St. Louis Railroad (steam) and the Lake Shore (electric). In 1895 the steam road carried 42,526 passengers but in 1902 it carried only 9,795 passengers, the electric road in the same year carrying 3,896,902 passengers."

The Lackawanna & Wyoming Valley Railway Company, operating a double track system between the cities of Scranton and Wilkes-Barre, Pa., carried, during the four months ending October 1906, 1,396,833 passengers. This railway, 18 miles in length, competes with two double-track steam railways having excellent terminals in both cities, and with a third double-track steam railway having an equally good terminal in Scranton, but a less favorably located terminal at the Wilkes-Barre end of the line. The electric railway charges 30 cents for the ride between the two cities and sells round-trip tickets for 50 cents. Except at certain hours, it operates its service upon 10 minutes' headway. At least one of the steam railways, in the endeavor to retain its passenger business, has reduced its rate to 40 cents for the round trip. It has also increased the frequency of its train service. We have been unable to ascertain the number of passengers carried by the competing steam lines during the four months above referred to, but the earning power of frequent electric service is strikingly demonstrated by the fact that this railroad, operating in competition with three double-track steam railways of practically identical length and substantially equal terminal facilities, should be doing a business which represents an income of $5.00 per capita per annum of tributary population, including that of the terminal cities.

ELECTRIFICATION OF TRANSPORTATION SYSTEMS IN MANHATTAN AND THE BRONX—EFFECT UPON TRAFFIC

A study of the transportation statistics of New York City, particularly during the last decade, is not only of great local interest, but is instructive as illustrating the effect of improvement in transit facilities upon gross receipts.

The data graphically summarized in Figs. 1, 2, and 3 have been compiled from official records; those subsequent to June 30, 1883, being obtained from the reports of the State Surveyor and of the Railroad Commission of the State of New York. The effects of improved service are clearly evident from an inspection of these figures.

In Fig. 1, the line marked "All lines" indicates for each year ending June 30, the aggregate paid fares collected by all surface, elevated, and subway lines in the Boroughs of Manhattan and Bronx. It will be noticed that the aggregate paid fares for the year ending June 30, 1894, and also for the following year, were slightly less than for the year ending June 30, 1893, this reduction doubtless being due to the hard times which then prevailed. With this exception, the aggregate of paid fares for all lines shows in each year an increase over the preceding year. Comparing the Manhattan System for the year 1893 with the same system for the year 1899, a decrease of 21% in paid fares is shown. During the same period the paid fares of surface lines, which meanwhile in large degree had adopted electric operation, increased by 43%. That the decrease in

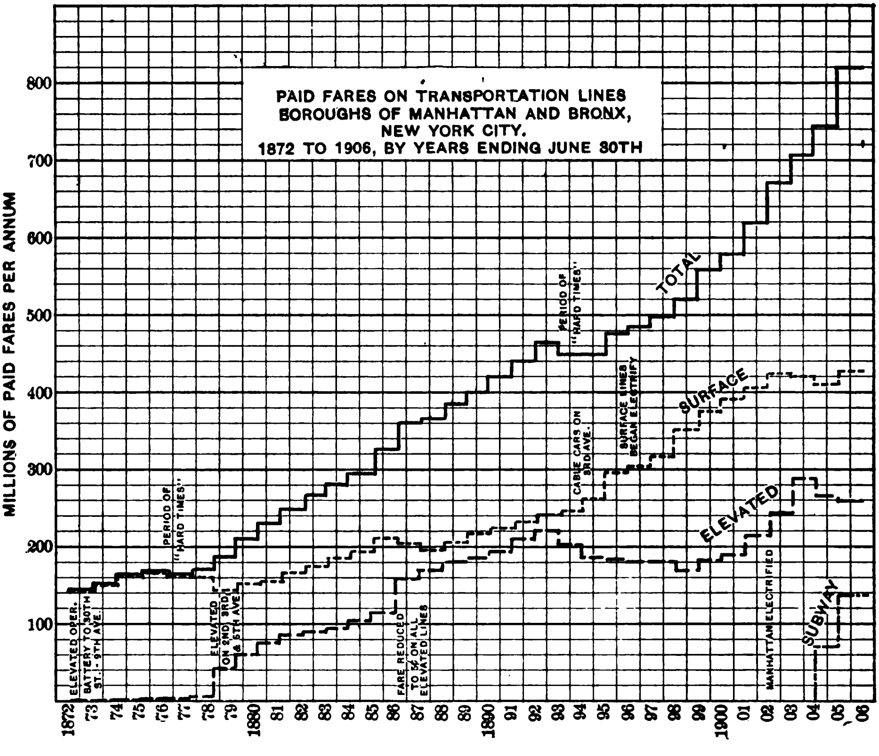

FIG. 1.

business on the elevated lines was not due to any decrease in the service, is shown by Fig. 2, from which it will be seen that the car mileage operated increased steadily during this period. The unavoidable inference is that the diversion of traffic to the surface lines was a direct result of the improved service offered by the latter.

During the year ending June 30, 1901, the last fiscal year of steam operation on the elevated lines, the Manhattan system

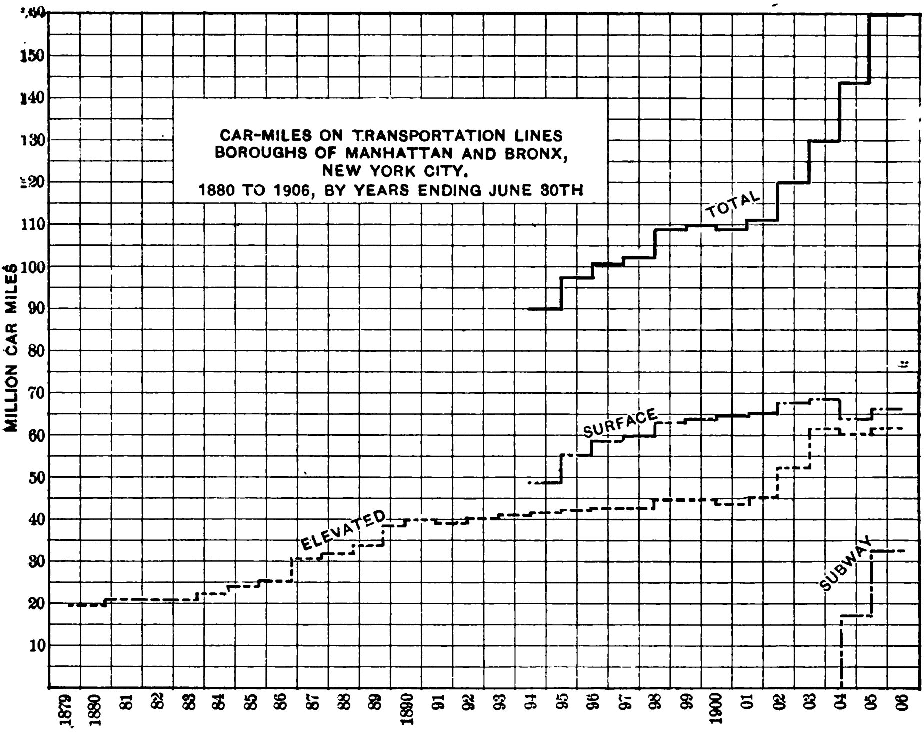

FIG. 2.

collected 190,045,741 fares. The surface lines collected 388,108,794 fares. During the year ending June 30, 1904, the Manhattan System, now operated by electricity, collected 286,634,195 fares, an increase of 50%, while the surface lines collected 419,423,092, an increase of about 8%. In the following year, 1904, the subway began operation, and both elevated and surface lines recorded a decrease in fares collected.

In Fig. 4 are plotted curves showing the population of, *a*, Greater New York and, *b*, the Boroughs of Manhattan and the Bronx. The points which fix these curves from 1860 to 1900

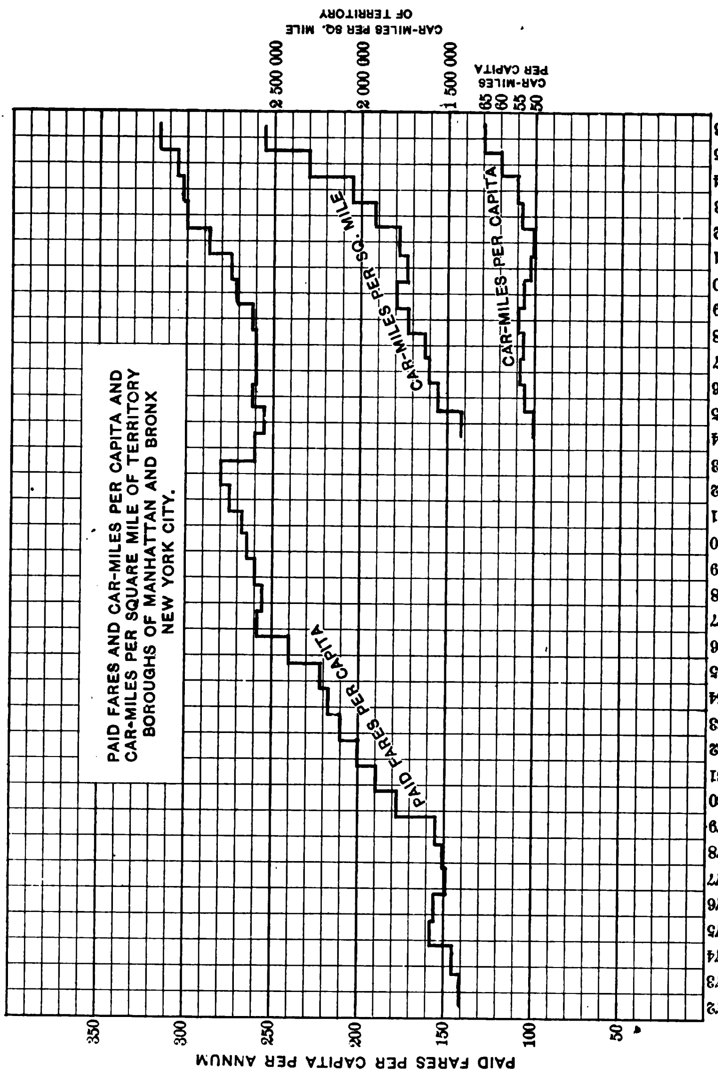

Fig. 3.

inclusive, are from the United States Census Reports. For the years 1910 and 1920 the estimated population is based upon the average rate of change in the per cent. increase per

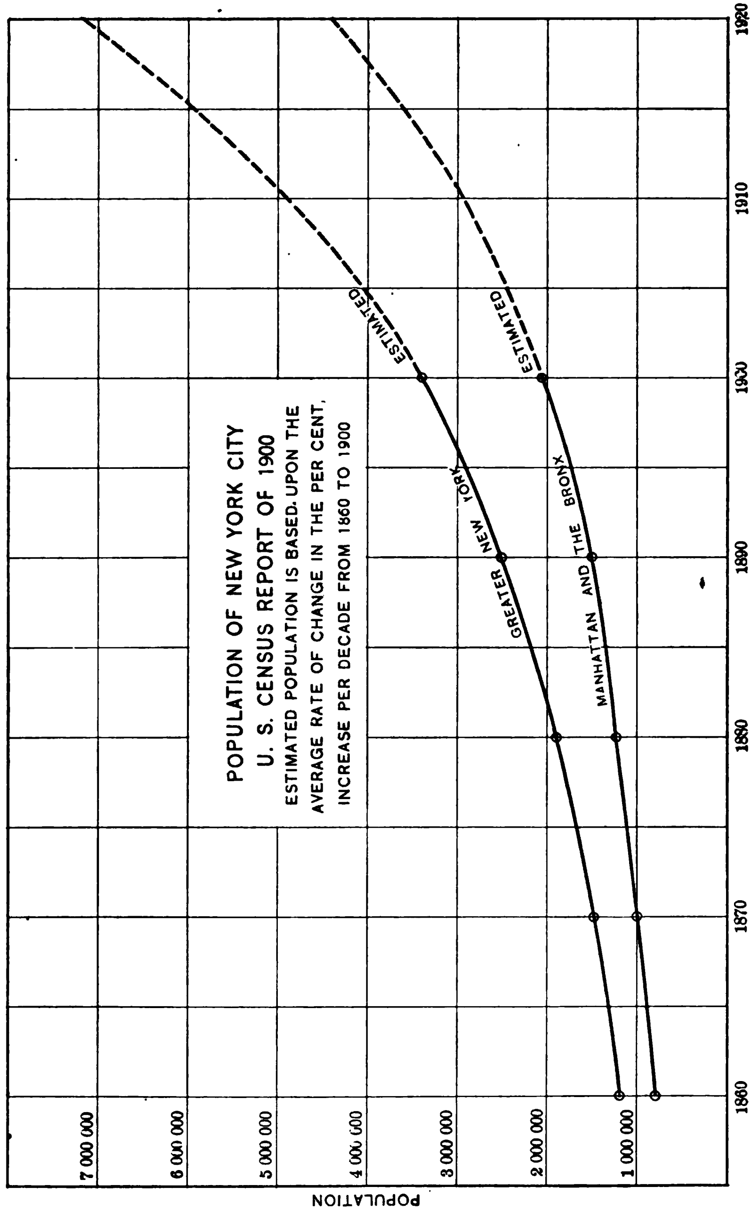
POPULATION OF NEW YORK CITY
U. S. CENSUS REPORT OF 1900
ESTIMATED POPULATION IS BASED. UPON THE
AVERAGE RATE OF CHANGE IN THE PER CENT,
INCREASE PER DECADE FROM 1860 TO 1900
GREATER NEW YORK
MANHATTAN AND THE BRONX
ESTIMATED
ESTIMATED
7 000 000
6 000 000
5 000 000
4 000 000
3 000 000
2 000 000
1 000 000
POPULATION
1860
1870
1880
1890
1900
1910
1920

Fig. 4.

decade from 1860 to 1900. Up to 1905, the population as indicated in these curves is undoubtedly not far from the fact; for 1910 and 1920 the probable populations indicated are interesting, although the curves take no account of the effect of improved transit facilities between Manhattan and Long Island, and between Manhattan and New Jersey.

Notwithstanding the very rapid increase in population of the Boroughs of Manhattan and Bronx from 1890 to 1905, the paid fares collected by the several transportation systems have increased still more rapidly, as shown in the curve of paid fares per capita in Fig. 3.

In the same figure are shown the increase in car-miles per capita per annum, and in car-miles per annum per square mile of territory served.

While it is not directly pertinent to this discussion, we would here call attention to a fact of great importance to those responsible for the development of the systems of transportation in the City of New York; viz., the fact that while for the year ending June 30, 1906, the subway carried 137,919,632 passengers, the aggregate carried by the elevated and surface lines was but 23,684,957 less than the aggregate carried by these lines during the year ending June 30, 1904, the last fiscal year before the subway began operation. In other words, comparing the year 1906 with 1904, the aggregate paid fares on elevated, surface, and subway lines, increased by 114,234,675, which is about three-fourths the ultimate capacity of the present subway. It is evident from inspection of these curves, that the existing systems are destined to be still further and greatly overcrowded before additional subways can be completed.

It is of course impracticable in studying the results of improved service in the electrification of elevated, surface, and subway lines in New York, to attempt to differentiate the causes which have contributed to the increased traffic. While that increase has been due undoubtedly in large part to the improved service offered, it is also obvious that the number of passengers carried would have increased very materially by the growth of population, even had no improvement in the old conditions of service been effected. But it cannot be too strongly emphasized, that while from one point of view improved transit facilities are a result of increased population, from another and equally tenable point of view, increased population is a result of improved transit facilities.

COMPARATIVE COSTS OF OPERATION.

As the standard with which to compare our estimates of cost of electric operation, we have adopted the grand average results obtained in operation by steam locomotives upon the existing railways of the United States, as set forth in the report of Statistics of Railways for 1904 compiled by the Interstate Commerce Commission, and proof-sheets of the report of the Commission for the year 1905. We shall follow the classification of operating expenses adopted by the commission, and generally used by the railroad companies in their annual reports. The estimated costs of electric operation being approximately determined as compared with the grand averages obtaining in steam railroad practice in this country, the work of determining, for any given case, the relative advantages and disadvantages of steam and electric operation will perhaps be facilitated. We compare, of course, the itemized operating expenses in the case of operation by electricity with corresponding expenses under existing conditions of steam motive power equipment. In estimating operating expenses of electric equipment, we have based conclusions upon results obtained in practice so far as we possess the necessary data.

The substitution of electric for steam equipment involves a large investment in power plant, and in electric conductors and apparatus for conveying power from the power plant to the moving trains, The distributing system for alternating-current equipment, which is the only class of equipment deserving serious consideration in connection with the general problem which we are discussing, comprises an addition to permanent way equipment in the form of overhead construction and electrical conductors conveying power from the power house to the trolley or conductor which is carried above the track. At the present time, the limit of potential generally adopted in this country in constructing alternating-current dynamos is 11,000 volts. Where this voltage is generated, and the distance from the power house to the section of railroad to be electrified does not exceed 25 or 30 miles, step-up and step-down transformers are unnecessary. For greater distances, higher potentials are used upon the feeder circuits between power house and trolley, transformers for increasing the generated potential being installed in the power house, and transformers for lowering the potential to that selected for the trolley; *e.g.*, 11,000 volts, being located in suitable transformer houses at intervals of from 30 to 50 miles, depending chiefly upon density of traffic.

For the trolley, a potential of 11,000 volts is suitable and can be adequately insulated. The mechanical support for the trolley comprises, preferably steel poles with brackets or light steel bridges spanning the track.

The cost of the power plant and distributing system are properly chargeable to capital account.

Our estimates are based upon the assumption that single-phase alternating-current equipment is used; that the trolley potential is 11,000 volts; that each power-house supplies railway line to a distance of 150 miles in each direction, the feeder potential employed being 60,000 volts; that the overhead construction is first class in every respect, steel bridges and steel poles set in concrete being used exclusively for the support of both trolley conductors and feeders.*

As regards equipment of the rolling stock, it is the general practice of our railways to charge against operating expenses all new equipment purchased to replace that which has been worn out in service. In the adoption of electricity, it would seem that this method might be followed in general by our more important railway systems, the substitution of electric equipment beginning naturally upon those parts of the system where the resulting advantages are maximum. In other words, worn-out locomotives, etc., on such a system might be replaced by electric equipment and the cost of the equipment charged against operation, just as the cost of new steam locomotives otherwise required would be charged against operation. For example, the Erie Railroad system, on June 30, 1906, had 1333 locomotives in service. Taking no account of increases necessitated by growth of the company's business, not less than 60 new locomotives should be added to this equipment each year to take the place of those worn out in service. The cost of these new locomotives under steam operation would be charged against " Repairs and renewals of locomotives," and it would seem that their value expended for electric equipment to replace them might be similarly charged. In addition to the purchase of new locomotives to replace those worn out in service, our railroads are compelled from year to year, by the

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*In assuming the use of the single-phase system we are not condemning other systems. The three-phase system has not received from American engineers in general, that degree of consideration which its possibilities and demonstrated advantages justify. Its use, at least on mountain-grade divisions, can be supported by very strong arguments.

growth of their business, to purchase additional locomotives and other rolling equipment. While these are usually charged against capital account in one form or another, it may be pointed out that any method of financing their cost which may be adopted is equally applicable to electric locomotives.

In cases where the initial substitution of electricity is on a large scale, as compared with the total rolling stock equipment of the railroad making the change, it is probable that a part if not all of the cost of electric rolling stock equipment will generally be charged to capital account.

We proceed to compare the cost of electric operation with the cost of operation by steam locomotives, using as our standard of comparison the grand average results in steam operation in the United States for the years 1901–1905, inclusive. These average results are set forth in the following tables compiled from the reports of the Interstate Commerce Commission and printed on the three following pages. Many of the items included in this tabulation vary between wide limits in the practice of different railroads.

MAINTENANCE OF WAY AND STRUCTURES

Under the general heading, " Maintenance of Way and Structures," item No. 1, " Repairs of Roadway," if changed at all should show some reduction under conditions of electric operation, but obviously no material change is to be expected. We assume therefore that this item, amounting to 10.818% of total operating expenses, will remain unchanged.

The items, " Renewals of rails," " Renewals of ties," and " Repairs and renewals of bridges and culverts," may be conveniently grouped. In the aggregate, these on the average steam operated railroad amount to 6.33% of the total cost of operation. If the electric locomotive be substituted for the steam locomotive, it is safe to predict that this group of items of expense will be reduced; but it is practically impossible to state with accuracy what the reduction will amount to. In general, it is obvious that the substitution of electric locomotives developing equal draw-bar pull, with axle-loads reduced at least 25% as compared with steam locomotives, and with wheel-bases not exceeding those of steam locomotives, should favorably affect these items. From the best study which we have been able to make of the detailed factors comprised under these three items of the classification, it would seem that under

TABLE I

Item	Amount 1905	Per cent.					Average Five Years	Estimated Cost of operation by Electricity
		1905	1904	1903	1902	1901		
Maintenance of Way and Structures......	274,415,279	19.784	19.519	21.185	22.255	22.272	21.003	22.354
1. Repairs of roadway	144,161,701	10.393	10.348	11.093	11.331	10.294	10.818	10.818
2. Renewals of rails..	18,259,022	1.316	1.298	1.386	1.521	1.676	1.439	5.00
3. Renewals of ties...	36,856,864	2.657	2.519	2.487	2.838	3.140	2.728	
4. Repairs and renewals of bridges and culverts..........	32,166,990	2.319	2.228	2.461	2.593	2.730	2.466	
5. Repairs and renewals of fences, road-crossings, signs and cattle-guards.....	6,179,686	0.446	0.437	0.527	0.625	0.598	0.527	0.527
6. Repairs and renewals of buildings and fixtures..........	29,320,204	2.114	2.147	2.590	2.562	2.417	2.366	1.300
7. Repairs and renewals of docks and wharves..........	2,883,274	0.208	0.209	0.235	0.220	0.283	0.231	0.231
8. Repairs and renewals of telegraph...	2,374,932	0.171	0.179	0.165	0.173	0.158	0.169	0.169
9. Stationery and printing..........	383,158	0.028	0.029	0.032	0.031	0.029	0.030	0.030
10. Other expenses....	1,829,448	0.132	0.125	0.209	0.361	0.317	0.229	0.229
Repairs and renewals of track bonding..............								0.800
Repairs and renewals of overhead construction......								3.250
Maintenance of Equipment.............	288,012,604	20.765	19.967	19.133	19.127	18.629	19.524	12.287
11. Superintendence ..	7,831,965	0.565	0.567	0.559	0.601	0.599	0.578	0.578
12. Repairs and renewals of locomotives.	114,988,428	8.290	7.904	7.408	7.246	6.695	7.509	2.253
13. Repairs and renewals of passenger cars............	27,342,129	1.971	1.951	2.044	2.157	2.277	2.080	2.080
14. Repairs and renewals of freight cars.	113,723,239	8.199	7.777	7.442	7.432	7.436	7.657	6.000
15. Repairs and renewals of work cars.....	3,360,390	0.242	0.231	0.242	0.245	0.233	0.238	0.238
16. Repairs and renewals of marine equipment...........	2,650,543	0.191	0.154	0.177	0.215	0.234	0.194	0.194
17. Repairs and renewals of shop machinery and tools.....	9,186,101	0.663	0.704	0.696	0.643	0.605	0.662	0.500
18. Stationery and printing..........	595,571	0.043	0.042	0.046	0.044	0.043	0.044	0.044
19. Other expenses....	8,334,240	0.601	0.637	0.519	0.544	0.507	0.562	0.400

NOTE.—It is customary with some railroads using electric equipment to include under the general heading "Maintenance of Equipment," the maintenance of the power plant and electric transmission systems. Both of these, however, are more conveniently treated by including them in the cost of electric power delivered to the overhead trolley system or third rail.

TABLE I.—*Continued.*

Item	Amount 1905	Per cent. 1905	1904	1903	1902	1901	Average Five Years	Estimated Cost of operation by Electricity
Conducting Transportation	769,613,017	55.486	56.670	55.893	54.671	54.979	55.540	43.603
20. Superintendence	25,007,322	1.803	1.779	1.742	1.711	1.726	1.752	1.752
21. Engine- and round-house men	130,437,844	9.404	9.550	9.562	9.401	9.340	9.451	4.710
22. Fuel for locomotives	156,429,245	11.278	12.128	11.675	10.776	10.602	11.292	5.702
23. Water supply for locomotives	9,147,590	0.660	0.659	0.614	0.623	0.612	0.634	0.000
24. Oil, tallow, and waste for locomotives	5,442,970	0.392	0.397	0.389	0.366	0.361	0.381	0.250
25. Other supplies for locomotives	3,295,384	0.238	0.248	0.232	0.218	0.206	0.228	0.228
62. Train service	90,654,520	6.536	6.735	6.677	6.737	7.011	6.739	6.739
27. Train supplies and expenses	21,963,086	1.583	1.581	1.552	1.500	1.471	1.537	1.000
28 Switchmen, flagmen and watchmen	60,141,422	4.336	4.386	4.313	3.984	3.848	4.173	4.173
29. Telegraph expenses	24,823,266	1.790	1.788	1.754	1.784	1.785	1.780	2.000
30. Station service	89,304,658	6.438	6.605	6.664	6.832	6.947	6.697	6.697
31. Station supplies	8,961,573	0.646	0.686	0.667	0.676	0.672	0.669	0.669
32. Switching charges, balance	4,201,050	0.303	0.280	0.244	0.272	0.319	0.284	0.284
33 .Car per diem and mileage, balance	18,835,325	1.358	1.358	1.400	1.480	1.618	1.423	1.423
34. Hire of equipment, balance	3,040,641	0.219	0.195	0.214	0.180	0.161	0.194	0.194
35. Loss and damage	19,782,692	1.426	1.279	1.094	0.990	0.819	1.112	0.750
36. Injuries to persons	16,034,727	1.156	1.196	1.120	1.048	0.911	1.086	1.000
37. Clearing wrecks	3,594,658	0.259	0.275	0.284	0.221	0.189	0.246	0.200
38. Operating marine equipment	9,903,479	0.714	0.696	0.745	0.721	0.862	0.748	0.748
39. Advertising	5,959,380	0.430	0.418	0.428	0.429	0.428	0.427	0.427
40. Outside agencies	19,688,261	1.419	1.411	1.449	1.579	1.615	1.495	1.495
41. Commissions	233,987	0.017	0.022	0.044	0.077	0.089	0.050	0.050
42. Stock yards and elevators	786,850	0.057	0.060	0.057	0.069	0.075	0.064	0.064
43. Rents of tracks, yards and terminals	23,947,881	1.727	1.563	1.544	1.519	1.724	1.615	1.615
44. Rents of building and other property	4,814,407	0.347	0.382	0.411	0.440	0.440	0.404	0.404
45. Stationery and printing	8,772,789	0.632	0.640	0.642	0.622	0.638	0.634	0.634
46. Other expenses	4,408,010	0.318	0.353	0.376	0.416	0.510	0.395	0.395

TABLE I.—*Continued.*

Item	Amount 1905	Per cent. 1905	Per cent. 1904	Per cent. 1903	Per cent. 1902	Per cent. 1901	Average Five Years	Estimated Cost of operation by Electricity
General Expenses.....	55,022,127	3.965	3.844	3.789	3.947	4.120	3.933	3.933
47. Salaries of general officers...........	11,676,616	0.842	0.841	0.823	0.925	0.984	0.883	0.883
48. Salaries of clerks and attendants...	18,582,142	1.340	1.313	1.254	1.244	1.262	1.283	1.283
49. General office expenses and supplies.............	3,459,470	0.249	0.230	0.234	0.249	0.257	0.244	0.244
50. Insurance.........	6,885,932	0.496	0.471	0.432	0.412	0.384	0.439	0.439
51. Law expenses.....	7,096,275	0.512	0.513	0.541	0.558	0.549	0.549	0.549
52. Stationery and printing (general expenses)........	2,439,781	0.176	0.170	0.175	0.168	0.161	0.170	0.170
53. Other expenses....	4,861,911	0.350	0.306	0.3330	0.391	0.447	0.365	0.365
Recapitulation of Expenses...........								
54. Maintenance of way and structures	274,415,279	19.784	19.519	21.185	22.255	22.272	21.003	22.354
55. Maintenance of equipment........	288,012,604	20.765	19.967	19.133	19.127	18.629	19.524	12.287
56. Conducting transportation.........	769,613,017	55.486	56.670	55.893	54.671	54.979	55.540	43.603
57. General expenses..	55,002,127	3.965	3.844	3.789	3.947	4.120	3.933	3.933
Grand Total......	1,387,043,0	27100.	100.	100.	100.	100.	100.	82.177

electric operation they should be reduced about one-fourth; in other words, they should approximate 5% of the total operating expenses. It is not to be imagined, of course, that railroads adopting electric traction would limit themselves to equal draw-bar pull and not increase loads. They would, naturally, take advantage of the possibility of increasing draw-bar pull so far as strength of draft-gear may permit, thereby effecting gains far outweighing the decrease in operating expenses represented by saving in maintenance of roadway, rails, and ties, which would result from a decrease in the weight of locomotives. This argument is valid, not only with reference to high-speed passenger traffic, in which the hammer-blow of the engine is emphasized, but also in connection with freight traffic, where in recent years there is a marked tendency to employ trains of great length and locomotives of extreme weight.

The cost of track-maintenance is increased by reason of the electric bonding of the rails. This bonding, including the cost of special bonds necessary where an automatic track signal system is used, will cost about $500 per mile under average conditions. Its cost of inspection and maintenance should not exceed $50 per mile of single track per annum.

The annual cost of " Renewals of rails," " Renewals of ties," and " Repairs and Renewals of bridges and culverts," averages in the United States $400 per mile of track, which as above stated, is 6.633% of average operating expenses, under steam operation, and for equal trains, as we have estimated, 5% for electric operation. The effect of the cost of track-bonding, therefore, would increase the items under consideration by about one-eighth, which is equivalent to an increase of 0.8% in operating expenses. To avoid possible confusion, we include the cost of " Repairs and renewals of track bonding " as a separate item in the column " Estimated Cost of Operation by Electricity."

Under the general conditions which will govern where electricity is substituted for steam in railway operation, there can be no doubt that the substitution will result in a material reduction in the cost of maintenance of rails, ties, bridges, and culverts. In this substitution electric locomotives will be used for freight traffic, while for passenger traffic locomotives will be eliminated ultimately and multiple-unit car equipments employed. For the immediate future, however, locomotives will be employed not only for freight traffic but also in some cases for passenger traffic, for the practical reasons which have impelled the Pennsylvania, the New York Central, and the New York, New Haven & Hartford systems in electrifying their New York terminals to adopt electric locomotives for handling their through trains.

The hammer-blow upon rails, is largely and in some cases wholly avoided by the adoption of electricity; *e.g.*, the entire electric equipment of the heavy locomotives used in the Baltimore tunnel is spring-borne; this is true also of the 70-ton Ganz locomotives recently placed in operation upon the Valtellina, and of the single-phase locomotives ordered by the New York, New Haven & Hartford Railroad. In the case of the locomotives recently constructed for the New York Central Railroad the motor armature is carried by the axle. The armature and axle weigh 7460 lb.; obviously the hammer-blow, even in this case, is not to be compared with the tremendous blow due to unbalanced reciprocating parts, the inertia of which in steam locomotives at high speeds is sufficient actually to lift the wheels from the track.

The hammer-blow is less serious at the speeds at which freight trains usually travel; but even if we ignore entirely the effect of the unbalanced parts in this case, the electric locomotive still possesses the important advantage that its ratio of tractive effort to weight is much higher than that of the steam locomotive.

The most striking feature in American railway operation in recent years is the increase in length of train and weight of locomotive, under pressure of business which has increased at a ratio much exceeding the ratio of increase in track mileage. Despite the efforts of our railway engineers and managers, the roadbed has not kept pace with this advance; and while the weight of rail has been increased materially, the factors of safety as regards weight upon ties and bridges, and particularly as regards the security of rails against displacement due to side-thrust on curves, are by no means what they should be, and yet apparently have reached their limit. Lieut.-Col. Yorke, Chief Inspector for the British Board of Trade, in his report of the results of his observations in the United States in 1903, called particular attention to this fact, and expressed the opinion that American railway practice is tending towards British practice in respect to the distribution of weight on ties secured by inserting chairs between the rails and the ties.

In view of the fact that our railways have been spending large sums of money to increase the stability of the roadbed, to strengthen bridges and culverts, and to maintain rails in position upon the ties, the advantage which the electric locomotive possesses in its higher ratio of tractive effort to weight is important, even in freight traffic at low speed. The necessity of utilizing track capacity to the utmost, and the economies resulting from the operation of long trains, have resulted in gradually increasing the length and weight of freight trains until it would appear that the limit has been reached, unless further improvement in draft-gear, track, and roadbed, and further increase in weight of locomotives, be found possible. It is evident, however, that if electric locomotives operated by the multiple-unit system could be used and located at suitable distances throughout the train, the possible length of a freight train would not be limited by its practicable motive power equipment.

Operation of electric locomotives thus located presupposes upon all roads the addition of control-wiring and couplers to freight cars. The report of the Interstate Commerce Commission for 1904 shows that of a grand total of 1,845,304 locomotives and cars operated by our railways, 1,823,030 are equipped with automatic couplers and 1,554,772 are fitted with train brakes. At the present time, the cost of train-line and couplers would approximate $75 a car, but a reasonable cost for the apparatus required, if furnished in large quantities, would not exceed $50 per car.

As regards the making up of trains, it is now necessary to couple the air-line between cars, and the additional labor of connecting the control-couplers would not be serious.

While the cost of equipping freight cars, and of additional labor involved in connecting trains, is very small as compared with the immense advantages which in many cases would result from the ability to distribute locomotives at suitable intervals in a freight train, and control them simultaneously and perfectly by the hand of the engineman at the head of the train, the probability of adoption of multiple-unit operation for freight trains appears remote, since there is apparently no sufficient reason why a railroad company not adopting electricity should equip its cars for electric operation over the lines of another company which may adopt the newer motive power. Whether it be possible for a company desiring to avail itself fully of the advantages of electric traction for freight, as well as for passenger traffic, to bring to bear upon other lines interchanging freight with it, pressure sufficient to induce those lines to spend $50 per freight car for electric equipment is a question outside the scope of our present consideration.

Reverting to Table I, item 5, " Repairs and renewals of fences, road-crossings, signs and cattle-guards," will not be changed by the adoption of electricity.

Item 6, " Repairs and renewals of buildings and fixtures," includes repairs and renewals of engine houses and shops, also water tanks and coal-handling apparatus. Under electric operation, it is evident that this item would be materially reduced. This subject will be further discussed when we come to consider item 12, " Repairs and renewals of locomotives." It is conservative to say that for the operation of a given train-mileage, under the average conditions of railway service in this country, the number of electric locomotives required should not exceed one half the number of steam locomotives now used. The reduction in the number of locomotives implies, of course, a reduction in the cost of repairs and renewals of engine house and shops, and taking this into account, in connection with the elimination of water tanks and coal-handling apparatus, distributed along the line, it is our opinion that this item will be reduced from 2.366% to about 1.3% of the total annual operating expenses.

Item 7, " Repairs and renewals of docks and wharves " obviously will not be affected.

Item 8, " Repairs and renewals of telegraph." It is probable that this item will be somewhat increased in general where electric operation is adopted. The effect upon the operating expenses, however, is so slight as to be practically negligible in our consideration of the general problems of comparative expenses of steam and electric service.

Item 9, " Stationery and printing " will not be changed.

Item 10, " Other expenses " we may assume will not be affected.

Under the general heading " Maintenance of Way and Structures," the classified statement of operating expenses of a railroad electrically equipped includes the following items in addition to the foregoing:

a. " Repairs and renewals of track bonding."

This has been referred to in our discussion of items 2, 3, and 4, and it is included in our tabulated statement as a separate item amounting to 0.8% of operating expenses.

b. " Repairs and renewals of overhead or third-rail construction."

From detailed calculations of the cost of high class overhead construction, where two tracks are to be equipped the cost of overhead construction is approximately $10,300 per mile. This includes trolley conductors equivalent to No. 4/0 wire B. & S. gauge, insulated for 11,000 volts alternating, and supported by steel cables, carried by substantial steel bridges set in concrete, and spanning the tracks. For single-track work using steel poles and brackets and catenery support, the cost closely approximates $4800 a mile.

Of the total line mileage of the United States in 1905, amounting to 216,974 miles, approximately 0.4 are in double track, including yards and sidings for single-track lines, and 0.6 are single-track.

The grand average cost of overhead steel construction of the type considered, therefore, closely approximates $5000 per mile of track. In this case, our estimate of the annual cost of " Repairs and renewals of overhead construction " cannot rest directly upon actual experience, since practically no overhead construction of this character is in use under the conditions of railway service. We may, however, base conclusions which should be reasonably correct upon consideration of first-class overhead trolley construction such as is used by our best interurban lines. Some light is also thrown upon the subject by extensive experience in the operation of high potential transmission circuits, and the experience of the Valtellina line is particularly instructive.

Light steel bridges, set in concrete, subject to the comparatively slight strains involved in supporting the light conductors required, should last almost indefinitely if kept properly painted. The absence of smoke and gasses from locomotives favors their long life. The cost of these steel bridges and poles is a large part of the overhead construction.

The wear of the trolley wire will depend upon density of traffic, but its original cost is only $700 a mile, and judging from the experience of ordinary trolley lines and the results obtained on the Valtellina its life should be long.

The steel catenary cables supporting the conductor being well galvanized should last many years without renewals.

Breakage of insulators, such as are now available, will not constitute a large item of expense.

As regards life of steel structures, it is instructive to note the fact that much of the structure of the Manhattan Elevated lines still in use is more than 30 years of age, and is apparently unimpaired notwithstanding the heavy and frequent traffic which it has carried and still carries.

It is probable that engineering opinion in regard to the amount which should be allowed for " Repairs and renewals of overhead construction " under consideration will not be unanimous, but taking into account all of the factors which appear to affect the problem, it is our judgment that the amount required should not exceed $150 per mile of track per annum. This is equivalent to $210 per mile of line per annum, the average ratio of track-mileage to line-mileage being 1.4 to 1.

The increase in operating expenses due to this item is about 3.25% the average operating expenses per line-mile in the United States for the year 1905 being $6451.00.

It is of course, possible to erect a much cheaper form of construction if wood poles be used. Though the first cost of such construction is low, it involves repairs and renewals constituting a much larger percentage of its cost than in the case of the steel bridge and pole construction set in concrete. The annual effect upon operating expenses with this type of construction as an average figure may be expected to approximate 2.5%.

" MAINTENANCE OF EQUIPMENT. "

Item 11. "Cost of superintendence " will not be changed.

Item 12. " Repairs and renewals of locomotives " amounts to 7.509% of the average operating expenses of our steam railroads. This item, as we find in the classification of operating expenses prescribed by the interstate Commerce Commission, " does not include the expense of cleaning boiler tubes and packing cylinders, nor ordinary regular inspection, this being charged to the item " Engine and Roundhouse Men." It does include " all expenditures for account of repairs and renewals and rebuilding of locomotives, tenders, snow-plows (when attached to locomotives), furniture and loose and movable tools and supplies used in connection therewith. It also includes the cost of locomotives, tenders and appurtenances thereunto belonging, built or purchased to make good the original number charged to construction or equipment."

As regards " Repairs and renewals of electric locomotives," actual experience to date is not sufficient to justify us in fixing a figure for this item which can be regarded as established. There is, however, evidence sufficient to justify an estimate which in the average case should be approximately correct.

Before considering data based upon experience, it is pertinent to remark that a moment's consideration of the constituent details of mechanism, their relative complexity, and their respective functions, leads directly to the conclusion that the repairs and renewals of an electric locomotive should be very small as compared with the same item of expense in the operation of a steam locomotive. If we imagine for a moment that electric locomotives had been in use for many years while steam locomotives had but recently come forward as competitors, and that the engineering world of to-day being familiar for years with the essential simplicity of the electric motor as applied to traction purposes, were now called upon to judge the comparative merits of the essentially complicated aggregation of mechanism which we call a steam locomotive, the verdict, as regards the relative cost of repairs and renewals to be expected, is obvious but the argument *a priori* cannot be conceded, and we proceed to consider such evidence based upon comparative results in actual service as we have been able to secure.

1. INTERBOROUGH RAPID TRANSIT CO., MANHATTAN DIVISION.

In the operation of the Manhattan Railway under steam and electric traction, respectively, data for interesting comparisons are afforded; although owing to the fact that in this case multiple-unit electric equipment, applied to two-thirds of the cars constituting the trains, has been substituted for the steam locomotive, the comparison is less favorable to electric operation so far as this item of expense is concerned than it would be were electric locomotives used. The reason is found in the relatively great complication of multiple-unit equipment as compared with locomotive equipment; as a result of this the number of parts in this case is multiplied in the approximate proportion of three to one, and the cost of repairs and renewals is therefore radically increased beyond what it would be were electric locomotives employed.

For the year ending June 30, 1901, the car-mileage operated by the Manhattan Railway was 43,860,158. The cost of repairs of locomotives was $173,609, or 0.39 cents per car-mile.

For the year ending June 30, 1906, the car-mileage operated by the Manhattan Railway was 61,723,112. The cost of repairs of the electric equipment, including lamps, lamp wiring, and heaters, was $171,927, or 0.28 cents per car-mile.

Had electric locomotives been used instead of the multiple-unit system, the number of parts constituting the electric equipment, as stated, would have been about one-third that now in use. These parts would have been larger and more expensive than the corresponding individual parts constituting the multiple-unit equipment, but the cost of repairs of the aggregate electrical equipment (which is largely labor of inspection) probably would not exceed 60% of the present cost. The results are further influenced unfavorably to electric traction as regards this comparison by the fact that the speed, and consequently the power consumption per car, have been radically increased, and by the fact that the repairs and renewals of lamps, heaters, and wiring are included.

A careful consideration of the detailed factors involved has led us to the conclusion that had electric locomotives been substituted for steam locomotives, and had the weight and speed of trains not been increased, the cost of repairs of electric equipment would have approximated 0.2 cents per locomotive mile. We estimate also that the cost of repairs to these small locomotives exclusive of their electric equipment operating under the existing conditions would not have exceeded 0.2 cents per locomotive-mile, and that the total cost would have approximated one-fourth of the cost of the corresponding item under steam traction. This figure of course is available only as a ratio in our consideration of the general railway problem.

The very low cost which was actually obtained in the case of steam locomotives on the Manhattan; viz., 1.57 cents per locomotive mile, is explained by the extremely simple construction of the engines, the fact that they were not overloaded, were operated on an elevated structure, and were admirably maintained. It is also to be noted that the [amount expended for repairs was minimized in view of the contemplated adoption of electricity.*

In applying to the general railroad problem evidence afforded by Manhattan experience, it must be noted that the elevation of the tracks places the motors beyond the reach of the dust or cinders which the rush of a train at certain seasons raises from the average railway track. On the other hand, the fact that the average run between stations on the elevated system is only about 2000 ft. exposes both motor and control to the action of brake-shoe dust which is liberated in quantities many times as great as would be the case in average railway service, and this brake-shoe dust is far more injurious to both motors and control than is dust from disintegrated ballast or cinders.

In designing electric equipment for general railway service, it is advisable and not difficult to protect the motors effectively against the admission of dust of all kinds, particularly in cases where locomotives rather than multiple-unit equipment is adopted. This would be accomplished naturally by thoroughly enclosing the motor, and ventilating it by forced draft so directed as to prevent admission of dust.

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*In this connection it is interesting to note that the cost of maintenance of locomotive and average train under steam operation for the year ending June 30, 1901, was 4.2c. per train-mile while the cost in the case of an equivalent electric train, as shown by records for corresponding months for the year ending June 30, 1906, was 2.1c. per train-mile.

2. INTERBOROUGH RAPID TRANSIT COMPANY, SUBWAY DIVISION

For the year ending June 30, 1906, the car-mileage operated by the New York Subway was 31,931,073. The cost of repairs and renewals of electric equipment of rolling stock was 0.38 cents per car-mile. Estimating the probable cost of repairs and renewals of electric equipment, were electric locomotives in use instead of the multiple-unit car equipment, the approximate cost in this case works out at 0.7 cents per train-mile. A locomotive doing the same work as the electric equipment of the average train in the subway (about five cars) must be capable of exerting a draw-bar pull of 30,000 lb., which with 20% adhesion calls for 75 net tons on drivers. This is about double the weight on drivers of the average steam passenger locomotive, and the figure 0.7 cents per train-mile, obtained in actual service under conditions very severe in respect to maintenance of electric equipment, by reason of the presence of great quantities of brake-shoe dust, is to be compared with the cost of maintenance of steam locomotives exclusive of running-gear, frame, cab, and those other parts common to both electric and steam equipment.

3. WILKES-BARRE & HAZLETON R.R.

Operation for the year 1905:

Equipment comprises motor cars weighing 43 tons without passengers, and equipped with four 125-h.p. motors and multiple-unit control.

Effective draw-bar pull (20% adhesion) = 17,000 lb.

Speed of operation in local service = 30 miles per hour.

Total length of run = 27 miles.

Average number of stops = 6.

Car-mileage operated in 1905 = 262,947.

Cost of repairs and renewals of electric motors = $1,021.70 = 0.39 cents per car-mile.

This road operates in a mountainous country, ranging in elevation from about 500 ft. to 1700 ft. above sea-level. About one-third of the length of the road is on a grade of 3%.

4. LACKAWANNA & WYOMING VALLEY RAILROAD.

Operation for a period of four months ending October 31, 1906:

Equipment: *a*, 16 passenger cars, 77,500 lb. each; *b*, 14 passenger cars, 64,500 lb. each; *c*, 4 freight and express motor cars, 61,300 lb. each; *d*, 1 electric locomotive, 94,600 lb.

Car-mileage operated = 527,554.

Repairs and renewals of electric equipment = $4,450.43 = 0.84 cents per car-mile.

5. NIAGARA, BUFFALO & LOCKPORT RAILROAD.

Operation for a period of six months ending Nov. 30, 1906:

Equipment: passenger cars weighing about 60,000 lb., driven by four direct-current motors.

Average speed outside of Buffalo city limits, 20 miles an hour. Approximate number of stops one way trip: 30 on Buffalo & Niagara Falls division, and 6 on Buffalo & Lockport division.

Length of run outside of Buffalo, approximately 20 miles.

Car-mileage operated, 1,309,682.

Repairs and renewals of electric equipment, 0.79 cents per car-mile.

6. RETE ADRIATICA-VALTELLINA LINE.

Perhaps the best instance of electric operation directly comparable with cost of steam operation is afforded by the records of the actual results realized on the Valtellina line where both freight and passenger traffic are operated over a line 66 miles in length, traversing a very rugged country and in the winter exposed to severe climatic conditions. The equipment for the year ending July 1, 1904, comprised 10 motor cars and five 70-ton locomotives. The service performed amounted to 61,934,569 ton-kilometers. The average annual mileage of motor cars and locomotives amounted to 54,351 kilometers, while the steam locomotives superseded by electric equipment never exceeded an average of 29,000 kilometers.

The total cost of electrical and mechanical repairs to locomotives and motor cars, for the year ending July 1904, works out at 1.4 cents per locomotive or motor car-mile. During the last six months of 1906, the repairs to locomotives cost 1.8 cent per locomotive-mile. The rolling stock used on this line is excellent in design and construction and is particularly well adapted to operate in railway service at low cost of maintenance, by reason of the fact that three-phase motors and water rheostats are employed instead of commutating motors and switch-control. The equipment has not been operating long enough to have reached the point where renewals, as distinguished from repairs, have become necessary.

Summarizing the foregoing we have the following:

	Tractive effort 20% adhesion	Repairs of electric equipment of equivalent electric locomotive. Estimated
Manhattan Railway	22,000 lb	0.5¢
Subway train	33,000 "	0.7¢
Wilkes-Barre & Hazleton R.R.	17,000 "	0.38¢ (actual)
Lackawanna & Wyoming Valley R.R.	14,000 "	0.84¢
Niagara, Buffalo & Lockport R.R.	12,000 "	0.79¢
Rete Adriatica-Valtellina line Locomotives, complete cost of maintenance		1.8¢ (actual)

It may be conceded freely in respect to the foregoing data that they are neither sufficiently comprehensive in scope nor extended in respect to duration of service to justify definite and final conclusions. It must be noted also on the one hand that the cost of maintenance may be expected to decrease by reason of further improvement in the construction of apparatus of comparatively new types, and on the other hand that the costs given are for inspection and repairs rather than renewals, since the time has not arrived when any of this equipment has been thrown aside and replaced by new equipment charged to this item of operating expenses as is usual with steam railways.

The reports of the Interstate Commerce Commission do not show what proportion of the item, " Repairs and renewals of locomotives " is chargeable to renewals, but from inspection of detailed reports of our most important railway systems it seems fair to assume that in the case of the average railway from 4% to 5% of the total cost of repairs and renewals of locomotives represents the cost of renewals.

Taking into account all of the various considerations which must affect the conclusions in the general case, so far as we have been able to gather them, we are of the opinion that for equal draw-bar pull, the repairs and renewals of electric equipment of locomotives, assuming good design and construction according to present standards of the art, should not exceed 1 cent per locomotive-mile, and will probably approximate 0.9 cent per locomotive-mile.

Taking the higher figure, it is evident that the substitution of electric equipment for all parts of a steam locomotive other than frame, wheels, axles, cab, and other parts which are common both to electric and steam locomotive construction, a very great saving is effected. We have been unable to fix with satisfactory exactness a figure representing the average cost of repairs and renewals of these parts, but it would seem liberal to allow 1.5 cents per locomotive-mile, this being equivalent to an allowance of something over $400 per annum per locomotive. Taking this figure and adding the estimated costs of repairs and renewals of electric equipment, we have 2.5 cents per locomotive-mile as the estimated total cost of repairs and renewals of electric locomotives, performing the average work now done by steam locomotives.

In 1904 the aggregate revenue train-mileage operated was about 1,050,000,000. To cover locomotive mileage in switching, operating work-trains, and pushers we assume 1,300,000 locomotive-miles. In 1904 the aggregate repairs and renewals of locomotives was $105,633,752, the average cost per locomotive-mile, therefore, being 8.1 cents. A reduction to 2.5 cents, therefore, is equivalent to a saving of 70% in the cost of this item, or 5.256% of operating expenses, reducing this item to 2.253% of total operating expenses under electric operation.

In the foregoing consideration of the item repairs and renewals of locomotives, we have assumed equal locomotive mileage per day in steam and electric service. The item of expense under consideration will be proportional approximately to the mileage, and therefore we have made the comparison upon this basis.

The relative number of locomotives required for a given service is, however, a question of much importance and may here be appropriately referred to.

According to the report of the Interstate Commerce Commission for 1904, the aggregate train-mileage operated in the United States as above stated was 1,050,000,000. The locomotives in service numbered 46,743. The effective train-mileage, not including work-trains, pushers, or shifting mileage, was 58 miles per locomotive per day. We have been unable to ascertain from the report of the Commission what percentage should be added to this figure to cover accurately the locomotive mileage of work-trains and shifting and to take account of double headers and pushers, but inspection of the report of a number of our leading railways indicates that the effective train mileage averages from 70% to 75% of the locomotive mileage. It follows, therefore, that the daily run of the average locomotive in the United States is approximately 80 miles. Naturally there is a wide variation in the performance of locomotives on various lines; *e.g.*, passenger mileage as shown by reports of some of our leading railways varies from 90 miles to nearly 200 miles a day and individual cases are reported of locomotives making as much as 300 miles a day.

The average freight locomotive is actually on the road not more than 6 hours in each 24-hour period, and the same figure is approximately correct for the average passenger locomotive. In the case of electric locomotives there is no reason, so far as the mechanism is concerned, why it cannot be kept in practically continuous service. Ordinary inspection and maintenance require very little time, and if the equipment be well designed and constructed repairs of magnitude will be necessary only at intervals very infrequent as compared with steam practice.

The fact that the average daily run of the average locomotive is approximately 80 miles, is due in large measure to causes which would still exist were electric locomotives substituted. The time spent by freight locomotives in yards and terminals making up trains or awaiting opportunity to take their place in the processions of trains which in these days are demonstrating the insufficiency of track equipment for the business of the country, is a large factor. Perhaps this would not be greatly modified were electric locomotives employed. But other considerations which operate to reduce average mileage are the facts that the steam locomotive spends a large part of its life in the repair shop, and a still larger part in firing up and preparing for its work and in withdrawing fires, having boiler tubes cleaned, etc., after its daily run. Nothing short of years of actual experience can establish definitely the ratio of electric to steam locomotives required in average service, but it seems reasonable to assume that this ratio will not exceed 2 to 3 and will probably approximate 1 to 2. It will be noted that the foregoing estimate of cost of repairs and renewals is independent of any assumption as to the relative number of locomotives required since it is reckoned on locomotive mileage.

Item 13. "Repairs and renewals of passenger cars." In cases where electric locomotives are substituted for steam locomotives, there should be some reduction in this item. Painting should be considerably reduced by reason of the elimination of smoke. The life of the upholstery and interior decoration of the car will be increased.

Item 14. " Repairs and renewals of freight cars." This item will be favorably and very materially affected if it should ever prove practicable to operate heavy freight trains by locomotives located at intervals throughout the trains and controlled by the multiple-unit system. As has been pointed out, however, this will become practicable only when a large proportion of the freight cars in use are supplied with electric train line equipment. The bare possibility of this at present may seem fanciful, but those who realize the extent to which the wear and tear of freight cars results from the terrific strains to which the draft-gear is subjected under present operating conditions, especially on mountain grades, and who understand also the increase in track capacity and decrease in cost of train crews which would result from the adoption of a system which makes it possible, if necessary, to double the length and weight of the longest and heaviest freight trains now in use, will be ready to give this possibility serious consideration. The mere substitution of electricity for steam without altering the present make-up of trains, so far as location of the locomotive is concerned, makes it possible to operate two or more locomotive units at the head of the train, and to utilize their power to the utmost by multiple-unit control operated by a single operator on the leading engine.

Assuming that the methods of train operation remain the same, the adoption of electricity will still effect a reduction in the cost of Item 14, and for two reasons, viz;

1. The practical elimination of damage by fire which now frequently is superimposed upon damage caused by collision or derailment.

2. Reduction of wear and tear of wheels and brake equipment in descending long grades, by reason of the opportunity afforded to brake the trains by causing the motors to operate as generators. On lines where grades are heavy and of considerable length, the saving thus effected will be large. Generally speaking, the energy developed by the motors working as generators will be returned to the overhead circuit and utilized in coöperation with energy from the power house to furnish power to trains on the same division which may be ascending the grade.

No statistical data are available upon which to base an estimate of the probable reduction in this item to be expected from this cause. On comparatively level lines it will not be important, but on mountain-grade divisions it should operate to prevent a very large proportion not only of wear and tear directly due to grade but also of the destructive freight wrecks which are now so frequent. In the way of an estimate, nothing more definite than a guess based upon consideration of probabilities, and the views of various operating officials, can be advanced; but in the opinion of the writers the general substitution of electricity for steam operation in freight service should reduce this item from 7.657% to something like 6% of operating expenses.

Item 15. " Repairs and renewals of work cars," will not be changed materially.

Item 16. " Repairs and renewals of marine equipment," obviously will not be changed.

Item 17. " Repairs and renewals of shop machinery and tools," will be reduced under electric operation since the repairs to locomotives will be decreased radically as shown, and since the tool equipment required for the electrical machinery is materially less expensive and varied.

It would seem reasonable to expect that this item would be reduced from 0.662% to about 0.5% of total operating expenses. Of course a large proportion of the shop machinery and tools are for car repairs.

Item 18. " Stationery and printing," will not be changed.

Item 19. " Other expenses." The classification of operating expenses includes under this item " all expenditures for account of electric light, torches and lamps used in machinery department, shops, roundhouses and offices and the oil and material for the same; the proportion of labor and material for the proper operation and repair of electric lights used in connection with other departments; wages of engineers and firemen and the cost of fuel and water in operation of stationary engines or boilers for supplying power and heat to shops, buildings and roundhouses."

Other factors comprised are comparatively small and it is evident that the ability to use electricity for light and power purposes in shops, roundhouses and offices produced at a works cost of 0.6 cents and delivered to the point of consumption at a figure which on the average will approximate 0.75 cents will effect a material reduction in this item. We estimate that it will be reduced to about 0.4 cents.

CONDUCTING TRANSPORTATION.

Item 20. " Superintendence," will not be changed.

Item 21. " Engine and roundhouse men," includes in addition to the engine crew, round-house men whose work, of course, is chiefly in connection with the cleaning and maintenance of the engines. This item averages for the railroads of the United States 9.451% of the operating expenses, of which 91%, or about 8.6% of the operating expenses are for engine men and for firemen. Of this 8.6% approximately 5.5% is for engine men and 3.1% for firemen.

In considering the substitution of the electric locomotive for the steam locomotive it is obvious that the change eliminates the work which the fireman is employed to perform. The point is frequently made, however, that to reduce the engine crew to one man means an increase in the risk incurred in train operation and this point obviously is of such importance as to require careful consideration.

If we compare conditions which now exist upon such systems as the Manhattan Elevated with the conditions which existed before electricity was adopted, it seems reasonably clear that with a competent motorman operating a controller which instantly cuts off power and applies the brakes in case the hand of the motorman is removed from the handle of the controller, the safety of trains and passengers is assured in higher degree than it was under the old conditions. The usual argument against the elimination of the fireman is of course, found in the allegation that in case of the sudden death or serious illness of the engineman the fireman can take his place and bring the train to a stop or operate it to the next station. The controller which automatically cuts off power and applies the brakes cannot operate the train to the next station, but it can stop it much more promptly than the fireman possibly can, even when he is so located upon the engine as to be in sight of the engineman.

But a very large proportion of our steam locomotives are now designed in such a way that the engineman is not in sight of the fireman, and the mechanism of the steam locomotive which he controls has no automatic device for shutting off power and applying the brakes in case he suddenly dies at his post. In such an emergency on trunk-line railways there would be some advantage in the presence of the fireman, owing to the fact that if competent he could operate the train to the next station. This point might be met by having the train conductor or brakeman or flagman qualified to operate the electric train to its destination in case of accident to the motorman. The degree of skill required, so far as actual manipulation of the mechanism is concerned, would be far less than in the case of the fireman who in emergency might be entrusted with the responsibility of operating the steam train.

It would seem, therefore, that there can be no question of the reasonableness and safety of entrusting the operation of an electric locomotive to one man, provided the control system is equipped with effective appliances arranged to cut off the power and apply the brakes in case the motorman's hand leaves the hand of the controller.

As regards the wages of the engineman, the Manhattan Railway decided to pay its motormen the same wages which it had paid its enginemen. This decision was based largely upon consideration of the fact that familiarity with the road and experience in operating trains under the extremely close headway prevailing upon this system were of such importance that any risk which might be incurred by substituting new men must be avoided. The great majority of electrically equipped railways operating under conditions similar to the Manhattan, however, pay their motormen wages comparable to the wages of the men who operate street cars rather than to the wages of locomotive enginemen.

The work required of the motorman operating an electric train is far less onerous and is performed under conditions much less severe than is the case with the locomotive engine-driver, nor is the motorman in order effectively to perform his duties required to serve years of apprenticeship during which he must become familiar with the complicated mechanism under his control and competent to make upon the road any ordinary emergency repairs. The work required being relatively easy, the apprenticeship comparatively short, and the mechanical knowledge necessary greatly reduced, it is reasonable and proper that the compensation of the motorman, under average conditions, should be less than that of the engineman.

Apart from the attitude to be expected upon the part of employees, and aside from any question of sentiment, however, the management of a railway contemplating the substitution of electricity for steam would not be justified in lowering the standard so far as character and judgment are concerned, which are requisite for the motorman equally with the engineman. It must be remembered also that familiarity with the road and with signals, etc., are as important in his case as in that of his predecessor.

It is impossible of course to fix with definiteness a figure representing the wages of the motorman in railway service as compared with that of the engineman whom he may succeed, but it seems reasonable to assume that under average conditions the services of thoroughly competent motormen can be obtained at a figure which will represent a reduction of 1% in operating expenses, making this item 4.5% instead of 5.5%.

The expense for round-housemen, which under steam operation is about 0.85%, will be greatly reduced both by reason of the reduction in the number of locomotives required for a given service and also by reason of the demonstrated less cost of maintenance per locomotive unit. It is entirely liberal to allow for this item one fourth of its cost in steam operation, the saving here effected being equal to 0.64% of the average operating expenses of steam railroads in the United States.

The estimated cost of the item under consideration, therefore, is 4.71% of total operating expenses.

Item 22, " Fuel for locomotives." One of the marked economies resulting from the substitution of the electric motor for the steam locomotive in railway operation is in the reduction of the fuel account. The cost of fuel upon the average steam railway in the United States for the five years 1901 to 1905 inclusive constituted 11.292% of total operating expenses. The aggregate cost in 1905 was $156,429,245.

The following figures show comparative fuel consumption upon the Manhattan Railway during the year ending June 30, 1901, when steam locomotives were employed and during the year ending June 30, 1904, when electricity was used. During the period first mentioned one pound of coal produced 2.23 ton-miles, if the weight of the locomotive be included, and 1.5 ton-miles, if the weight of the cars only be considered.

During the latter period (electric traction) one pound of coal burned at the power house produced 3.85 ton-miles, excluding weight of locomotives; therefore, the ratio of ton-mileage per pound of coal in favor of electric operation was 2.57 to 1. Including weight of locomotive it was 1.72 to 1.

The average speed under electric operation was approximately 2 miles an hour greater than that attained by steam, and if correction be made for this difference the ratio of ton-mileage per pound of coal excluding weight of locomotives is approximately 3 to 1, and including locomotives 2 to 1 in favor of electric traction. It should be noted also that in this case the coal burned at the power house was of lower grade, and therefore less expensive than that used by the locomotives, and it is reasonable to expect that in general electric traction will mean utilization of cheaper fuel.

We would point out that the argument from Manhattan experience cannot be met by the statement that the Manhattan is not an average railroad. Were the steam and electric apparatus now operating the Manhattan lines applied to the operation of a division of a trunk-line railway, the one part of the system which would be affected in respect to efficiency is the high potential transmission lines, and the effect of their greater length in general would be to increase the relative fuel consumption of the electric system by not more than 5%. For trains drawn by locomotives the fuel account (coal only) under electric operation would still be approximately one-half of the cost of the fuel for steam operation, and for passenger service using multiple-unit equipment it would be less than 40% of the fuel used in equivalent steam service, even if we assume that the system of alternating transmission and conversion to direct current by synchronous converters be employed.

The advantage in favor of electric operation is even more marked if we assume that alternating-current equipment is to be used, as in general would be the case in the electrification of trunk lines or long divisions. In a particular case which we have worked out with great care, the trolley and track rail losses average 3.9%, the load factor being 0.33. This is the result obtained in using the single-phase system for the equipment of a division approximately 40 miles in length, the potential being 11,000 volts. The grand average of traffic in the United States does not exceed seven trains per day passing a given point in each direction, and the trolley and track rail energy losses for this traffic would be less than 2%.

Assuming that such a trolley voltage is used in connection with a feeder potential of say 40,000 to 60,000 volts, the allowable loss in these feeders at maximum load certainly will not exceed 10% and the energy efficiency of step-up transformers, transmission feeders, and step-down transformers will be 92%. Combining this figure with the energy efficiency of trolley and track, as above stated, the resultant efficiency from bus-bars of power house to the train will be 90%.

The works-cost of a kilowatt-hour at the bus-bars of the Manhattan plant is less than 0.6 cent when coal costs $3.00 per ton, this coal having a calorific value of 14,000 B.t.u. per lb. This cost includes fuel, water, labor, maintenance, miscellaneous supplies, and in short everything except capital charges. It is not abnormally low, the cost of both coal and labor being relatively high as compared with the grand average cost of equivalent coal and labor throughout the United States. Where fuel is less expensive, as in the middle West, large modern plants, using steam turbines, are producing the average kilowatt-hour at a price not exceeding 0.5 cent exclusive of capital charges, and in at least one case at a works-cost approximating 0.4 cent.

As will be shown hereinafter, were all the railroads of the United States to be operated by electricity, the average plant required, assuming power to be transmitted 150 miles, would approximate 4,000 kw. if the plants supplied but a single line 300 miles in length. The great bulk of the total power supplied however, would be derived from large plants in which the cost of producing the unit of energy, considering average costs of fuel and labor, should be less than 0.6 cent. While the small plants would exceed this figure we believe that as a grand average 0.6 cent is ample to cover the case. In this connection, it may be remarked that water powers and other sources of cheap power supply would tend to keep down the average cost of power under the assumed condition of electrification of the entire railroad system of the country.

In the case of the single-phase, 25-cycle motor, assuming the average length of run for freight trains to be 15 miles and for passenger trains 20 miles, we have calculated that of the energy delivered to the locomotive approximately 86% will be effective for traction in the case of the passenger locomotive, which is gearless, and about 84% in the case of the freight locomotive, which uses single-reduction gear. Combining the two, it is safe to say that of the energy supplied at the bus-bars in the power house not less than 75% will be effective for traction in the average locomotive equipped with this apparatus.*

The cost of a kilowatt-hour effective for traction therefore

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*For the motor curves upon which these figures are based, we are indebted to the courtesy of the Westinghouse Electric & Mfg. Co.

is 0.8 cent and the cost of a horse-power hour effective for traction about 0.6 cent of which 0.35 cent is for fuel when coal of 14,000 B.t.u. per lb., costs $3.00 per ton of 2240 lb., and 0.25 cent is for other power-house supplies, power-house labor, and maintenance of power-house equipment.

As we have stated, the railroads of the United States in 1905 used coal costing $156,429,245. For the purpose of estimating the cost of equivalent electric power the following data are necessary, of which those marked by an * are furnished by the report of the Interstate Commerce Commission while the others involve certain assumptions:

PASSENGER SERVICE

*Passenger train-miles.
Passenger car-miles.
*Passenger-miles.
Average weight of passenger trains:
  a. Weight of locomotives.
  b. Weight of cars.
  c. Weight per passenger.
Average speed of passenger trains.
Average length of run.
*Mail and express train-mileage.
Average weight of mail and express trains.
Non-revenue ton-mileage.

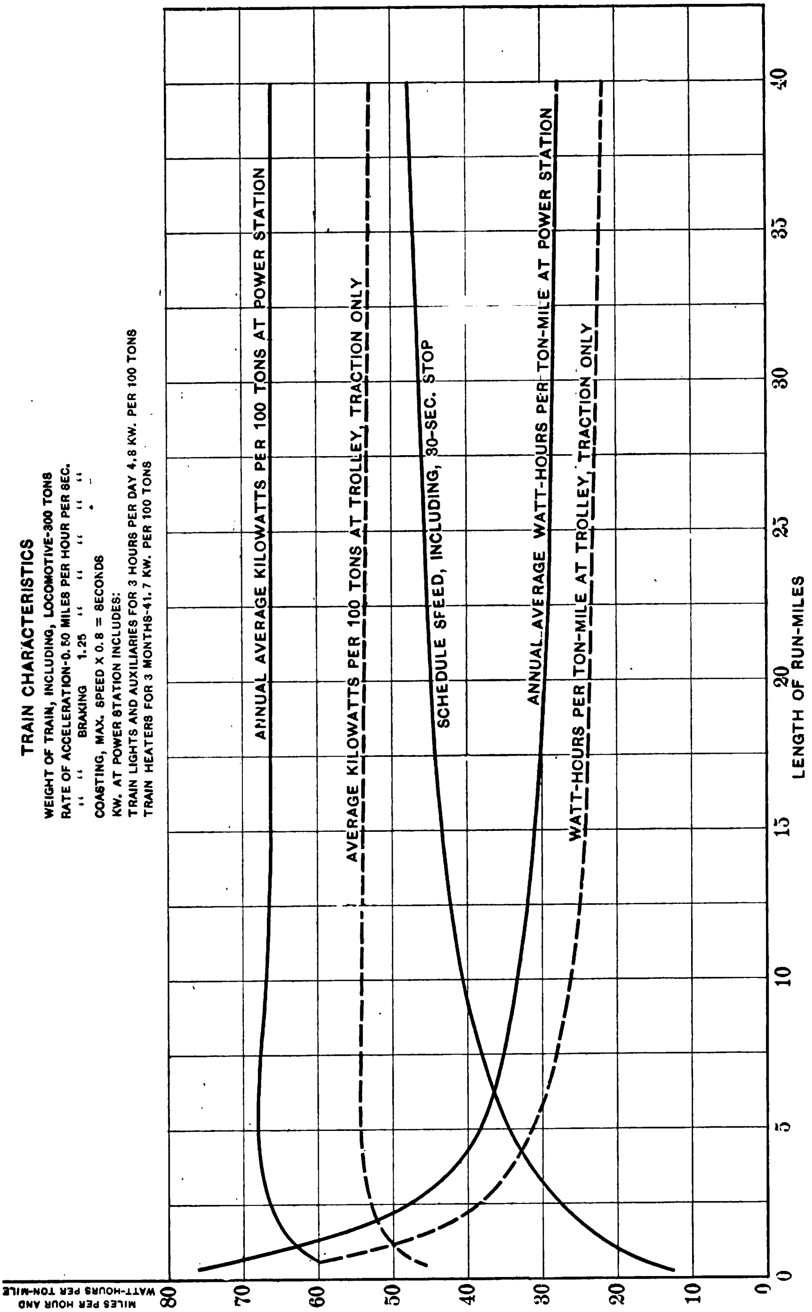
FREIGHT SERVICE

*Freight train-mileage.
*Freight car-mileage.
*Revenue freight ton-miles.
Average weight of freight trains:
  a. Weight of locomotive.
  b. Weight of cars.
Average speed of freight trains.
Average length of run.
Non-revenue ton-mileage, work-trains, switching, etc.

Referring to the several items in the foregoing lists not directly derived from the report of the Interstate Commerce Commission the assumptions made are as follows:

PASSENGER SERVICE

Passenger Car-Miles: These we have calculated from the stated train mileage and the assumption that the average number of cars per train is 5.5.



TRAIN CHARACTERISTICS

WEIGHT OF TRAIN, INCLUDING, LOCOMOTIVE-300 TONS
RATE OF ACCELERATION-0.50 MILES PER HOUR PER SEC.
" " BRAKING 1.25 " " " " "
COASTING, MAX. SPEED X 0.8 = SECONDS
KW. AT POWER STATION INCLUDES:
TRAIN LIGHTS AND AUXILIARIES FOR 3 HOURS PER DAY 4.8 KW. PER 100 TONS
TRAIN HEATERS FOR 3 MONTHS-41.7 KW. PER 100 TONS

Fig. 5.

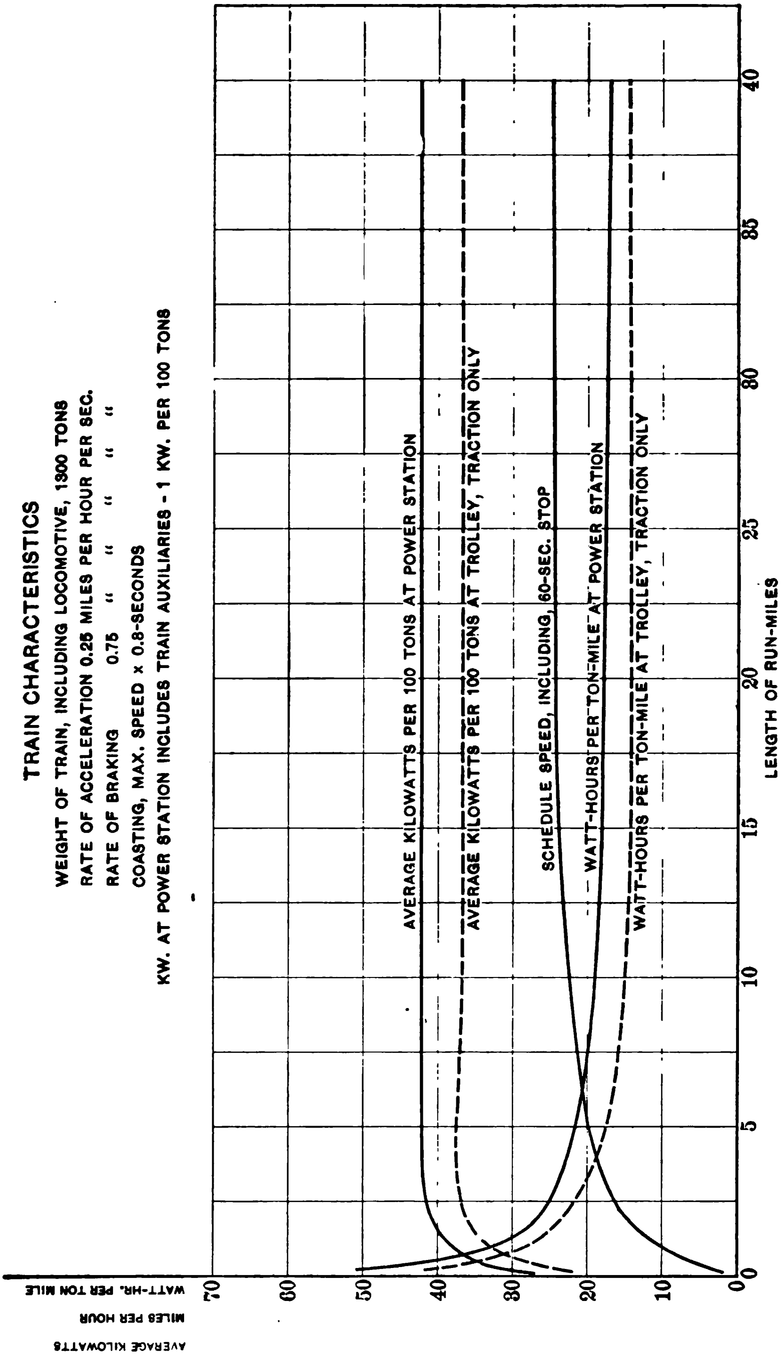

TRAIN CHARACTERISTICS
WEIGHT OF TRAIN, INCLUDING LOCOMOTIVE, 1300 TONS
RATE OF ACCELERATION 0.25 MILES PER HOUR PER SEC.
RATE OF BRAKING 0.75 " " " " "
COASTING, MAX. SPEED x 0.8-SECONDS
KW. AT POWER STATION INCLUDES TRAIN AUXILIARIES - 1 KW. PER 100 TONS
AVERAGE KILOWATTS PER 100 TONS AT POWER STATION
AVERAGE KILOWATTS PER 100 TONS AT TROLLEY, TRACTION ONLY
SCHEDULE SPEED, INCLUDING, 60-SEC. STOP
WATT-HOURS PER TON-MILE AT POWER STATION
WATT-HOURS PER TON-MILE AT TROLLEY, TRACTION ONLY
WATT-HR. PER TON MILE
MILES PER HOUR
AVERAGE KILOWATTS
70
60
50
40
30
20
10
0
5
10
15
20
25
30
35
40
LENGTH OF RUN-MILES

Fig. 6.

Average Weight of Passenger Trains: We assume,

a, Weight of the average locomotive exclusive of tender equals 60 tons—the weight on drivers is 38 tons—this is the weight of the average passenger locomotive used by the Erie system;

b, Average weight of ordinary passenger coaches without live load equals 30 tons. This weight is somewhat in excess of the average weight of cars used by a number of railroads using rolling stock undoubtedly representative of the average in use throughout the country. To this we have added 10% in estimating train weight to cover additional weight of Pullman cars.

c, Average number of cars in trains. We assume five and a half cars per train which is approximately correct for a number of the more important railroads and is probably slightly above rather than below the grand average.

d, Weight per passenger. We have assumed an average weight of 140 lb.

Average Speed of Passenger Trains: Referring to Fig. 5, the curve expressing the variation in the amount of energy required for traction as dependent upon average length of run between stations, shows that the increase resulting from a decrease in length of run from 20 miles to 10 miles is but 10%. If the average length of run be further decreased to 5 miles, the increase of energy for traction as compared with that required for a 10-mile run is approximately 18%.

Including energy required for heating and lighting the cars, it is not far from accurate to assume 33 watt-hours output at power-house per ton-mile in average passenger service.

Average Length of Run: We have assumed, as stated, 33 watt-hours at power house per ton-mile including light and heat. This corresponds to an average run of 10 miles.

Average Weight of Mail and Express Trains: We have assumed average weight of mail and express trains to be the same as that of the average passenger train, viz., 180 tons without locomotive or live load.

Non-Revenue Ton-Mileage: This is assumed at 10% to cover "double-headers," switching and additional power consumption due to grades and curves. The assumption is slightly less favorable to electric traction than the facts would probably warrant.

FREIGHT SERVICE.

Average Weight of Freight Trains: As regards freight service, in estimating the average weight of trains we have assumed the following:

a, Weight of locomotives equals 68 tons on drivers. This is the actual average of the freight locomotives of the Erie system exclusive of tender.

b, Weight of cars equals 15 tons. This figure closely approximates the average weight of all freight cars belonging to the Erie Railroad Company.

Average Speed of Freight Trains: Our curves (Fig. 6) are based upon a gear ratio which produces on straight and level track a maximum speed of 25 miles an hour.

Determination of the error involved by any mistake in our assumption of the average speed in freight service is facilitated by Fig. 8, which shows, for example, the following relations:

Maximum Speed.	Average speed, including 60 seconds stop, miles per hour.	Average watt-hours per ton-mile at power station.
20	19	17
25	23	18
30	27	19

Average Length of Run: We have assumed that for all freight service the average length of run is 15 miles. The actual average length of run may vary considerably from the distance assumed without causing material error in our calculation as shown in Fig. 6.

Non-Revenue Ton-Mileage: We have added 15% to the tota revenue earning ton-mileage to cover switching and pusher service and increased power consumption due to grades and curves.

Basing our calculations upon the foregoing statistical facts and the assumptions noted, we estimate that for the operation of the entire freight and passenger service of the United States as existing in 1905, the aggregate energy required at bus-bars of power houses would approximate 13,200,000,000 kilowatt-hours per annum.

At 0.6 cent per kilowatt-hour the total cost of energy for traction, for the operation of all auxiliaries, and for the supply of light and heat to passenger trains would closely approximate $79,000,000 per annum. This figure represents a saving of about

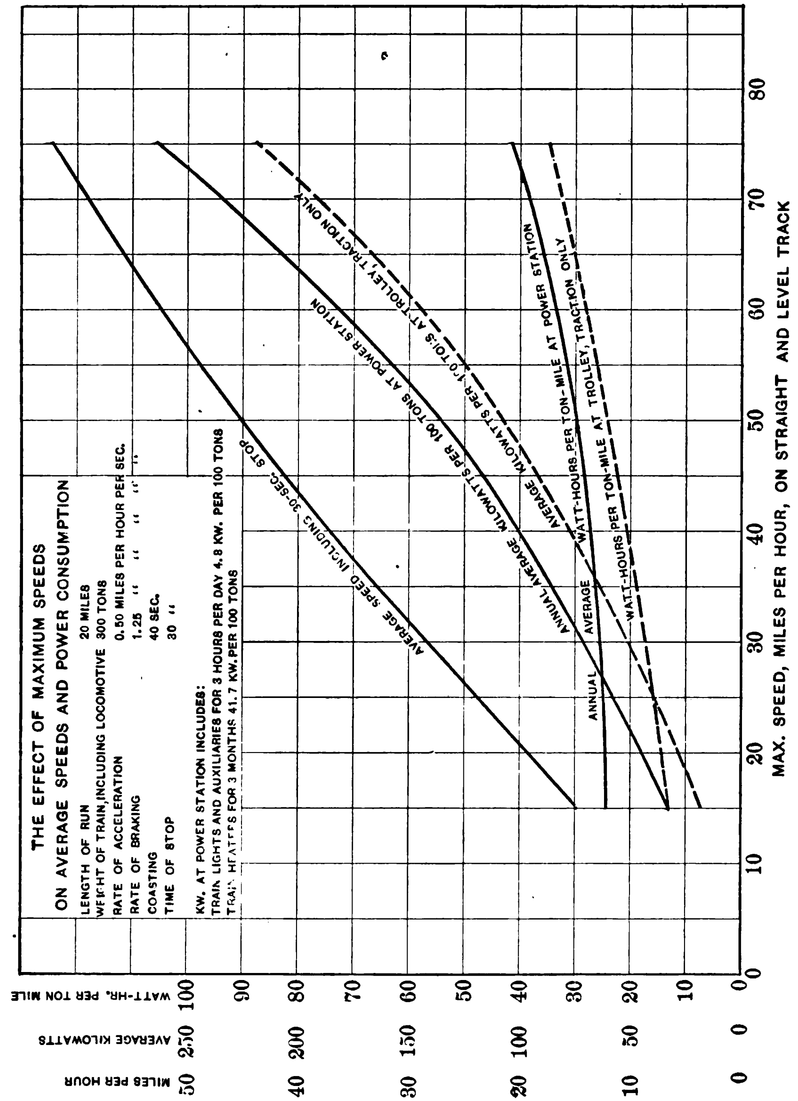

THE EFFECT OF MAXIMUM SPEEDS
ON AVERAGE SPEEDS AND POWER CONSUMPTION
LENGTH OF RUN 20 MILES
WEIGHT OF TRAIN, INCLUDING LOCOMOTIVE 300 TONS
RATE OF ACCELERATION 0.50 MILES PER HOUR PER SEC.
RATE OF BRAKING 1.25 " " " " "
COASTING 40 SEC.
TIME OF STOP 30 "
KW. AT POWER STATION INCLUDES:
TRAIN LIGHTS AND AUXILIARIES FOR 3 HOURS PER DAY 4.8 KW. PER 100 TONS
TRAIN HEATERS FOR 3 MONTHS 41.7 KW. PER 100 TONS
AVERAGE SPEED INCLUDING 30-SEC. STOP
KILOWATTS PER 100 TONS AT POWER STATION
KILOWATTS PER 100 TONS AT TROLLEY, TRACTION ONLY
ANNUAL AVERAGE
ANNUAL AVERAGE
AVERAGE
AVERAGE
WATT-HOURS PER TON-MILE AT POWER STATION
WATT-HOURS PER TON-MILE AT TROLLEY, TRACTION ONLY
WATT-HR. PER TON MILE
AVERAGE KILOWATTS
MILES PER HOUR
100
90
80
70
60
50
40
30
20
10
0
250
200
150
100
50
0
50
40
30
20
10
0
10
20
30
40
50
60
70
80
MAX. SPEED, MILES PER HOUR, ON STRAIGHT AND LEVEL TRACK

FIG. 7.

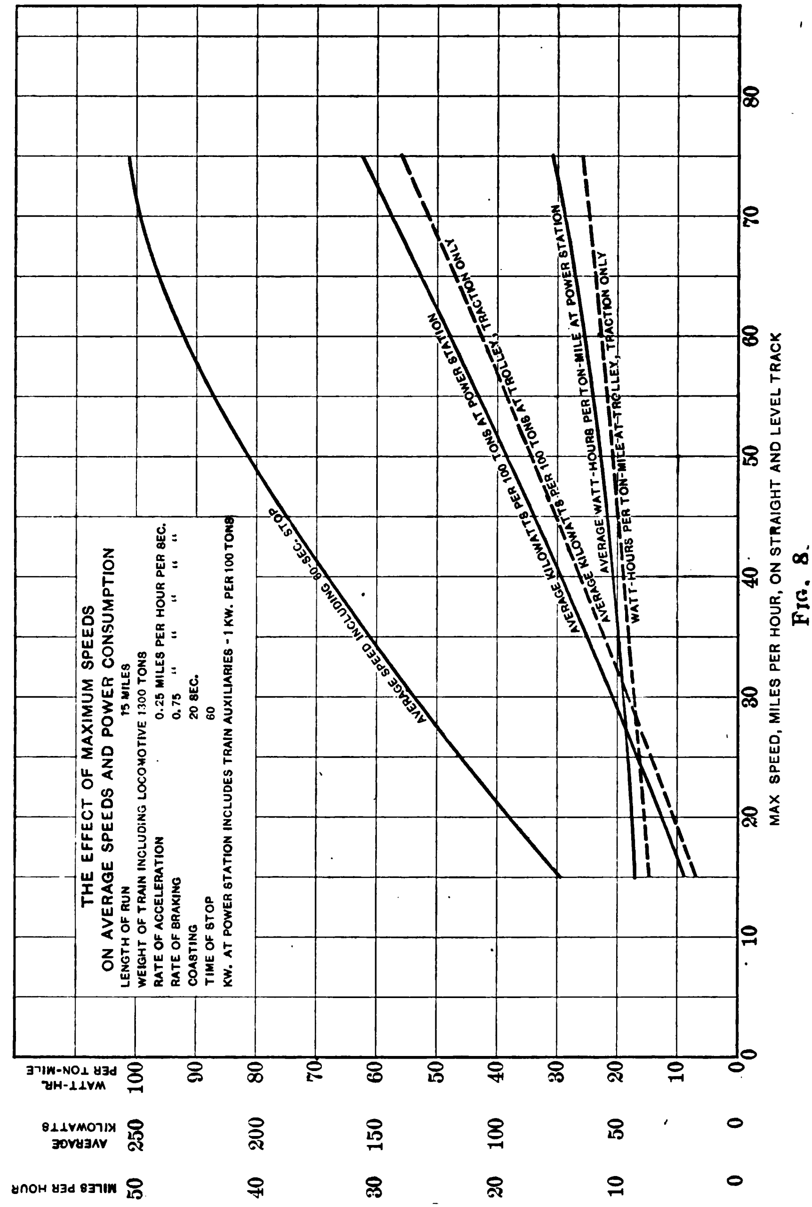

THE EFFECT OF MAXIMUM SPEEDS
ON AVERAGE SPEEDS AND POWER CONSUMPTION
LENGTH OF RUN 15 MILES
WEIGHT OF TRAIN INCLUDING LOCOMOTIVE 1300 TONS
RATE OF ACCELERATION 0.25 MILES PER HOUR PER SEC.
RATE OF BRAKING 0.75 " " " "
COASTING 20 SEC.
TIME OF STOP 60
KW. AT POWER STATION INCLUDES TRAIN AUXILIARIES - 1 KW. PER 100 TONS
AVERAGE SPEED INCLUDING 60-SEC. STOP
AVERAGE KILOWATTS PER 100 TONS AT POWER STATION
AVERAGE KILOWATTS PER 100 TONS AT TROLLEY, TRACTION ONLY
AVERAGE WATT-HOURS PER TON-MILE AT POWER STATION
AVERAGE WATT-HOURS PER TON-MILE AT TROLLEY, TRACTION ONLY
MAX SPEED, MILES PER HOUR, ON STRAIGHT AND LEVEL TRACK
0
10
20
30
40
50
60
70
80
WATT-HR. PER TON-MILE
100
90
80
70
60
50
40
30
20
10
0
AVERAGE KILOWATTS
250
200
150
100
50
0
MILES PER HOUR
50
40
30
20
10
0

FIG. 8.

$77,500,000 as compared with the coal used by steam locomotives in the year 1905.

Referring to the table, the average cost of this item for 5 years, viz., 11.292%, would be reduced by electric traction to 5.702%.

Item 23. " Water supply for locomotives." This item is eliminated if electricity be substituted for steam.

Item 24. " Oil, tallow, and waste for locomotives." This item should be considerably reduced. We assume that it will be reduced to 0.25%.

Item 25. " Other supplies for locomotives." We make no change in this item.

Item 26. " Train service." This item is not changed.

Item 27. " Train supplies and expenses." This item among many others includes the following which will be changed by the substitution of electric motive power, viz.: " Heating, lighting, cleaning and lubricating cars, including the cost of supplying and pumping gas into cars."

In discussing Item 22, we have included in the estimate of electric power required energy sufficient to light all cars three hours out of every twenty-four. We have also included energy sufficient to heat all passenger trains by electricity an average of three months per annum. Both of these are important items. The cost of cleaning the cars should also be reduced by the elimination of smoke and cinders from the locomotives. All things considered we believe it is fair to assume that under electric operation this item will approximate one per cent. of operating expenses.

Item 28. " Switchmen, flagmen, and watchmen " will not be changed.

Item 29. " Telegraph expenses." In general it is not to be expected that the large amounts of power required for train operation can be transmitted electrically under conditions which make it necessary to parallel telegraph lines by power circuits without more or less interference with the telegraph and telephone service. Certain technical questions in regard to methods of preventing interference remain to be worked out. The erection of overhead circuits carrying power supply will involve generally more or less shifting of the location of the telegraph lines. This item of expense is taken care of in our estimate by inclusion the in cost of overhead construction, and is treated as a capital account.

Telegraph circuits being rearranged with reference to the power circuits, or equipped with one or another of the devices which have been suggested as preventives of difficulties resulting from inductive effects of the power circuits, it might be assumed, perhaps with safety, that Item 29 would not be changed, but we are inclined to the opinion that there will be a slight increase in the cost of this item even under the best plans heretofore proposed, and we therefore increase it in our estimate to 0.2%.

Item 30. "Station service." Examination of the factors constituting this large item indicates no material change.

Item 31. "Station supplies." This item includes among many others the following, viz., "All expenditures for account of heating and lighting depots, waiting rooms, freight and passenger offices and other station buildings; fuel and supplies for engines operating freight carriers on docks, wharves and piers to convey freight between boats and cars; supplies used for stations and yards, signal lights, street lights, switch lights, semaphore lamps, etc., also bills of municipalities for lighting highway crossings."

The ability to employ conveniently for the lighting of important passenger stations and yards, electricity delivered at the point of consumption at a cost which, exclusive of capital charges upon power plant, closely approximates 0.6 cent per kilowatt-hour, to substitute electric motors for engines now used to operate freight carriers on docks, wharves, and piers, and to avail conveniently of electric hoists and telpher systems, are important advantages incident to the adoption of electricity. For lighting and incidental power service of this kind, equivalent to that with which railroads are now apparently satisfied, the change would undoubtedly mean reduction in cost. We will let it stand as it is, however, and would point out the fact that without increasing the cost of this item, a great improvement in facilities for handling freight at docks and wharves and for lighting passenger stations and yards will result from the substitution of electric power.

Items 32, 33, and 34. viz, "Switching charges, balance," "Car per diem and mileage, balance," and "Hire of equipment, balance," will not be changed.

Item 35. "Loss and damage," Under this item the important factors which will be affected by the substitution of electricity for steam are the following: viz., "Charges for loss, damage, delays or destruction of freight, parcels, express matter, baggage and other property entrusted for transportation (including live stock received for shipment) and all expenses directly incident thereto. * * * Charges for damages to or destruction of crops, buildings, lands, fencing, vehicles, or any property other than that entrusted for transportation, whether occasioned by fire, collision, overflow, or otherwise; also services and expenses of employees or others while engaged as witnesses in the case of suits."

For reasons which have been referred to in our discussion of the subject " Safety," it is clear that there should be a material reduction in the charges for loss due to destruction of freight, etc.

Another saving will result from the practical elimination by reason of damage of fire, which now not infrequently is caused by sparks from locomotives.

These savings will be offset to some extent by damage due to telegraph, telephone, or other wires coming in contact with the power circuits of the railway, unless reasonable care be exercised in preventing such accidental contact by the adoption of proper precautions when the electric equipment is installed.

In our estimate we have reduced item 35 to 0.75%.

Item 36. Injuries to persons." " This account includes all charges on account of employes or other persons killed or injured except lawyers' fees and court expenses."

For reasons referred to under the heading " Safety " some reduction in the number of passengers and employes killed and injured in railway accidents may be expected to result from the use of electricity. The risk of fire following collision being materially reduced, we should anticipate a relatively greater reduction in the number of passengers and employees killed in accidents caused by collision or derailment than in the number injured and a reduction in the average severity of non-fatal injuries may also be expected. On the other hand, a certain number of deaths and injuries will result directly from the use of electric power in large amount, by accidental contact with charged conductors. These accidents, however, should not be frequent if care is taken in the installation and proper maintenance of the electric equipment.

In the year 1904, of 10,046 fatal casualties reported by the Interstate Commerce Commission " 3,632 were sustained by employes, 441 by passengers and 5,973 by other persons. Of this last number 5,105 were reported as trespassing, from which it may be presumed that the railways are in no sense legally responsible for the deaths in question; suicides are included in this class."

"The number of injuries sustained by employees during the year was 67,000. The number of injuries sustained by passengers was 11,111 and the number of injuries sustained by persons other than passengers and employees was 7,977."

As regards the expenses included under item 36, we have no data indicating how these are divided other than the fact that the railroads apparently were put to little if any expense on account of about 80% of those persons other than passengers and employees who were killed and injured. While it is probable that a large part of the expenditures was on account of passengers killed and injured, and while any reduction in fatal and serious accidents to passengers therefore would materially affect this item, we have thought it best in the absence of satisfactory data to leave it practically as it stands, our estimate being 1%.

Item 37. "Clearing wrecks." In our opinion this item will be reduced under electric operation for reasons which have been sufficiently indicated in what we have said in regard to item 35. It would seem that 0.2% is a fair estimate of its probable amount.

The following items will not be changed:

Item 38, "Operating Marine Equipment."
Item 39, "Advertising."
Item 40, "Outside agencies."
Item 41, "Commissions."
Item 42, "Stock yards and elevator."
Item 43, "Rents of tracks, yards and terminals."
Item 44, "Rents of buildings and other property."
Item 45, "Stationery and printing."
Item 46, "Other expenses."

GENERAL EXPENSES

As regards the several items included under the heading "General expenses," the adoption of electricity will cause no material change.

SUMMARY AND CONCLUSIONS.

Our approximate estimate of the expenses chargeable to operation if electricity were in use to-day for the operation of all the railways in the United States, as discussed in the foregoing pages, is recorded in detail, item for item, in he last column of the tabulated data in Table I; these data with the exception of this column of estimates being the official records of the reports of the Interstate Commerce Commission. When considered in detail, the estimates are naturally subject to criticism more or less destructive, as in respect to many items we have not found opportunities to secure and investigate the great mass of detailed data showing in segregated form the scores of factors which are included in the aggregates appearing as single items in the summarized table of operating expenses; but while recognizing fully the imperfections and incompleteness of the attempted comparative analysis, we believe that the conclusions reached are correct within a reasonable degree of approximation.

According to our estimate, if all the railways of the United States were to-day operated by electricity using the single-phase alternating-current system at the potential adopted for the equipment of the New Haven Railroad, the energy required for operation being developed by power plants such as are to-day in extensive use and transmitted at potentials well within limits established in practical service, and if the rolling stock equipment consisted of locomotives and multiple-unit trains fitted with motors and control apparatus no better than the best which now exist, the aggregate cost of operation which in 1905 amounted in round numbers to $1,400,000,000, would be reduced by about $250,000,000.

To accomplish this result, power plants delivering about 13,200,000,000 kilowatt-hours per annum would be required. Assuming the radius of transmission from power houses to be 150 miles, the load-factor in railway service should be not less than 0.75, and taking this figure it appears that power plants capable of delivering a maximum output of about 2,800,000 kilowatts will be sufficient to operate the entire railway service of the United States as existing in the year 1905. The average output required is about 10 kilowatts per mile of line and 7 kilowatts per mile of track.

In 1905 the average gross earnings of our railroads per mile of line were $9,598, and the average operating expenses $6,409. The foregoing calculations lead to the conclusion that high-class electric equipment now available would reduce this average cost to $5,265. The difference is $1,144 per mile of line, against which apparent saving must be charged the annual interest and depreciation of the power plant, the addition to permanent way equipment, comprising overhead construction and track bonding, the transmission circuits, and the sub-stations with their equipment. Assuming 5% interest on cash cost of these items and allowing 5% for a sinking fund to cover depreciation of power house with its equipment and 2½% for a sinking fund to cover depreciation of the overhead construction and distributing system, the aggregate of fixed charges works out at $837 per mile of line. The saving in operating expenses, therefore, is more than sufficient to take care of the increase of fixed charges. In other words, it appears that the entire railroad system of the United States could be operated to-day at less cost by the electric motor than by the steam locomotive. That the railroads in general if so equipped would realize a large increase in earning power will be admitted by all who have given the subject intelligent attention.

In charging against electric operation 5% upon cost of power plant and 2.5% upon overhead construction, transmission circuits, substations, and track bonding, we have departed from methods usually adopted in financing American railway properties. If no depreciation be charged against the increased capital account represented by the items named, the apparent saving will be materially increased.

While our estimates have led us to the conclusion that, under average existing conditions of railway operation in the United States, improved financial results would be attained by the substitution of the electric motor for the steam locomotive, the immediate and general adoption of the new motive power by our railroad companies is neither possible or desirable. It requires no argument to demonstrate the wisdom of making haste with deliberation in a matter involving interests of such magnitude as those which are tied up with the transportation systems of the United States. Recognizing the magnitude of these interests and having in mind the fact that the art of electric traction as applied upon a large scale to heavy train units is yet young, the point which we desire here to emphasize is the necessity of conservative and carefully considered action upon the part of all members of this Institute who may be called upon to advise in respect to the electrification of railways now operated by steam.

Referring to the following tabulated results, in which we have applied the estimated reductions in operating expenses under electric traction, amounting to 18% of the present average operating expenses to the ten geographical groups into which the railroad systems of the United States are divided by the Interstate Commerce Commission, the relatively great advantages of applying electric traction to systems operating heavy traffic showing large gross earnings per mile of line are evident at a glance.

TABLE II.

COMPARISON PER MILE OF LINE—BY GROUPS STEAM AND ELECTRIC OPERATION.

(216,974 Miles Represented.) (Dollars per mile of line per year.)

Group No.	General Location	Miles of Line Represented	Gross Earnings	(Steam) Operating Expenses	(Electric) Operating Expenses	Difference Steam and Electric Operation	5% interest on Electrical Equipment Excluding Rolling Stock.
I	New England	8,094	$14,511	$10,493	$8,604	$1,889	$647
II	New York, Pa., et al	23,281	20,752	13,671	11,210	2,461	790
III	Ohio, Ind., Mich	25208	12,483	9,198	7,542	1,656	640
IV	Virginias, N. and S. Carolina	12,542	7,359	4,590	3,764	826	484
V	Kentucky, Fla., Louis, et al	24,563	6,867	4,899	4,017	882	475
VI	Ills., Wis., Dakotas, Ia., et al	48,672	8,021	5,169	4,239	930	525
VII	Mont., Neb., and Wyoming	11,546	7,737	4,092	3,355	737	461
VIII	Colo., Ark., Missouri, et al	30,456	6,362	4,308	3,533	775	461
IX	Texas and New Mexico	14,875	5,588	4,108	3,369	739	445
X	Pacific States	17,737	8,439	4,880	4,002	878	464
	United States, Total	216,974	9,598	6,409	5,255	1,154	516

THE STANDARDIZATION OF ELECTRIC RAILWAY TRACTION EQUIPMENT

Electricity, entering the field hitherto occupied exclusively by the steam locomotive, encounters conditions which greatly emphasize the necessity of prompt standardization of engineering practice. The management of our railways, beginning by electrifying terminals, tunnels, and mountain-grade divisions, will inevitably be led to extend these zones of electrification until they include divisions of very considerable length, and even trunk-line systems. To call attention to the transcendent importance of standarizing the location of such additions to permanent way equipment as the overhead trolley conductor and the third rail, is to demonstrate its necessity.

Electrical engineers now generally recognize the great value of established standards of frequency and potential in plants installed for lighting and power purposes. In recent years, the Institute, through its Standardization Committee has done splendid work for the manufacturer of electrical apparatus, as well as for the investor, by using its influence to promote the adoption of standards. Not many years ago, however, manufacturing companies, and consulting engineers, were in many cases prone to put forward or specify apparatus without reference to its ability to operate effectively in conjunction with other central station equipment, even when the latter was in actual operation in the immediate vicinity of the new plant. Fortunately, this tendency was less marked in the United States than it was, for example, in Great Britain. What will happen from a failure to adopt standards of practice at an early stage in the development of an industrial art of this nature, is well illustrated by the problem now presented in London, where the engineering advisers of the London County Council are engaged in studying the problem—how to supply electricity in bulk to 62 central-station plants producing electricity in bewildering variety of frequency and potential.

In the railway field, obviously, general principles are the same as in lighting; but wise foresight is more necessary and failure to exercise such foresight at this date less excusable. Moreover, the advocates of electric traction, unlike those who introduced the electric light into commercial service, are called upon to deal with a great body of trained engineers and experienced managers who are engaged in operating and extending systems of transportation which challenge admiration and respect. The rolling stock equipment of our railways, as a whole, is justly an object of national pride. The engineers and managers directing and controlling these properties are probably the equals of any body of men in the world as regards intelligence and experience. Obviously, it is of the utmost importance that they who accept the responsibility involved in the substitution of electricity for steam in the operation of certain parts of our great railways, should avoid fancies or fads and should in every way coöperate in the great work of evolving promptly standards of electric railway practice which shall withstand the test of time. The comparatively small beginnings of to-day will in all probability extend with a rapidity which we cannot now realize, and the confusion and loss which will inevitably result in the near future, if a variety of electric equipment be grafted at different points upon the existing railroad systems now operating by steam, may be imagined. The trouble and expense caused some years ago by the existence of several gauges of railway track in America were as nothing compared with what may result from a failure to establish promptly stanards of practice in the field of electric railway traction.

Where to-day are the "16,000 alternation" system of lighting, the "15,000 alternation" system of lighting, the "constant-current alternating-current arc light system," the "40-cycle system" and the "monocyclic system?" Where ten years from to-day will be the 1200-volt, or the 1500-volt, direct-current systems which have been suggested as substitutes for high-potential alternating-current systems in heavy electric traction?

While emphasizing the great importance of the early establishment of standards in the field of heavy electric traction, it must be recognized clearly that further inventions are liable at any time to modify views based upon present knowledge. The work of standardizing, therefore, should proceed with caution; but surely if present knowledge, not only of existing apparatus but of the lines along which applicable improvements must take place, is not sufficient to justify conservative application of the principle of standards, it is not sufficient to justify the investment of the very large sums which are now being expended for electric equipment.

Engineers constituting the membership of this Institute owe it to themselves, as well as to their clients, to use every effort without prejudice and without fad, to prevent waste by opposing the introduction of apparatus which, from its limitations, cannot solve the general problem of railway electrification; and it is to be hoped that they will use their united influence to fix proper standards as rapidly as this establishment may be consistent with progress.

Fortunately, knowledge of the possibilities and limitations of electric apparatus to-day is a very different thing from what it was in the early days of electric lighting. At the present time we have available theory so complete that electric science is less exact only than the science of astronomy and in applying this science in constructive work agreement between results carefully predetermined by calculation and those realized in practice is far closer than in any other comparable branch of engineering. There can be no doubt that it is possible to-day, in passing upon such a question, for example, as that of best frequency for railway operation to make a choice which shall withstand the test of time.

The necessity of proper standardization, is obvious. Specifically, it would seem feasible and eminently wise to agree upon standards of practice in respect to the following:

a. Location of third rail.

b. Location of overhead conductor used with single-phase alternating-current system.

c. Frequency of alternating-current traction systems.

It is equally desirable, but probably less easy, to agree upon a standard system of multiple-unit control for train operation.

THE QUESTION OF FREQUENCY.

While appreciating throughly and desiring to emphasize the importance of establishing and maintaining standards, it is also of the greatest importance that standards should be wisely chosen. The choice should be made, if possible, with full knowledge of the essential factors involved, and correct perspective view of their relative importance. It is with the feeling that so far as the frequency 25 cycles per second may be said to have become established, considerations obvious at first glance, but not properly controlling, may have influenced the choice unduly that we desire to present for discussion, the very important question whether 25 cycles per second or a lower frequency; *e.g.*, 15 cycles per second, is best adapted and should be established as a standard in the equipment of railways by electricity.

Final decision of such a question should be left neither to manufacturing companies, the management of which may be unduly influenced by commercial considerations, affecting their own immediate prosperity or convenience, nor should it be left to the individual consulting engineer. It is precisely the kind of question which the Institute should pass upon by the adoption of a recommendation carefully considered by its Standardization Committee. The manufacturing companies, which are largely and very influentially represented in the body of the Institute, will doubtless be willing to coöperate in the collection and study of the facts requisite to the formation of a well-grounded report.

While the adoption of a standard by the Institute has the force only of a recommendation, the American Railway Association perhaps might deem it wise to indorse the choice of the Institute. Such action on the part of these two bodies would go far definitely to establish the standard.

Comparing the relative advantages of 25-cycles and 15-cycles in railway service the salient advantages of the former are the following:

1. It is to-day in extensive use in plants developing and distributing energy for lighting and power purposes, and through sub-stations equipped with converters for the operation of many interurban lines. It has been adopted on a very large scale by such companies as the Interborough Rapid Transit Company of New York for the operation of its subway, surface, and elevated lines, by the Pennsylvania & Long Island Railway Companies for the electrification of New York terminal service and operation over a considerable part of Long Island, and by the New York Central for the electrification of its terminal service It is also the frequency developed by all of the great power plants at Niagara Falls, and from this source of power it is possible for all railway lines within a radius of 150 miles, or an even greater distance, to procure an ample supply of very cheap power.

It has been adopted by the New York, New Haven & Hartford Railway Company, the pioneer among American railroads in the adoption of the alternating-current motor in heavy railway traction, and by the Grand Trunk Railway for the electrification of the Sarnia Tunnel. Alternating current at 25-cycles is also utilized without the interposition of converters by the motor equipment on a dozen or more interurban trolley lines.

2. Our great manufacturing companies have drawings, patterns, and dies which enable them to manufacture conveniently and promptly practically all power-house and sub-station equipment required for 25-cycle apparatus. The weight of this consideration, however, is somewhat lessened by the fact that the march of progress—just now greatly accelerated by the general adoption of steam turbines—will undoubtedly cause a large proportion of existing drawings and patterns to be superseded probably in the very near future and certainly within the next five years.

3. The 25-cycle system is preferable to the lower frequency in the design of turbo-generators, since it affords wider range within which to select speed for units of various outputs. For very large units a frequency of 15-cycles, for example, requires either a 2-pole generator operating at 900 rev. per min., a 4-pole generator operating at 450 rev. per min., or a 6-pole generator operating at 300 rev. per min. Reduction in the number of revolutions per minute implies increase in diameter of the revolving element of generator and turbine, and in machines of large output the diameter of the revolving element in turbines of certain types may become too large for shipment in view of the limitations imposed by tunnels.

4. A frequency of 25 cycles permits convenient and effective lighting of yards and shops by incandescent lamps. It is also more favorable than a lower frequency as regards operation of induction motors for shop purposes.

Should our railways in general be equipped for electric operation, it is to be expected that in many cases they would undertake to supply electricity for light and power purposes beyond their own requirements, and the higher frequency possesses important advantages with reference to such commercial service.

For lighting and general power purposes in cases where service for lighting purposes that shall be thoroughly satisfactory in respect to voltage, regulation and continuity is requisite, commercial supply at 25 cycles would be preferable. Through the interposition of motor-generator sets or converters in combination with storage batteries in such cases either frequency is applicable.

5. The higher frequency possesses some advantage in respect to the ratio of tractive effort to weight upon drivers. The best information available to date appears to indicate that the difference between 25 cycles and 15 cycles in respect to

this consideration probably approximates 10%. Further data from actual test are desirable, and must be obtained before it is possible to estimate closely the weight of advantage possessed by the higher frequency.

6. The higher frequency is preferable for induction motors in railway service requiring a considerable range of speed adjustment. The force of this consideration depends upon the probability of using induction motors for traction purposes, and applies not only to the excellent three-phase motors, such as are in very successful use upon the Valtellina line, but also to the single-phase induction motor which, perhaps, is not beyond the range of probability. It is probable that in any general electrification of our railway system, induction motors will play a part by no means unimportant.

Without attempting detailed discussion, it is evident from the foregoing brief statement of the more important considerations in favor of 25 cycles that extremely weighty reasons must exist if the adoption of a lower frequency, *e.g.*, 15 cycles, is justified.

While our object in raising this question of frequency is to present it for discussion with a view to securing additional data and, if possible, a careful consideration of this very important question by the Institute through its Standardization Committee, or a special committee, and while we desire to avoid anticipating the verdict resulting from such an investigation, it is proper to state here that consideration of the facts now available leads us to conclude that notwithstanding the number and force of the arguments in favor of 25 cycles, a frequency of 15 cycles is preferable and should be adopted for heavy electric traction. The fundamental and, as it would appear, controlling reason which leads to this conclusion is the fact that within given dimensions a materially more powerful, efficient, and generally effective single-phase motor can be constructed for 15-cycle operation than is possible if 25 cycles be selected.

Final decision of the question whether the advantages of the 15-cycle motor as compared with the 25-cycle motor in respect to dimensions, weight, efficiency, power-factor, and commutation are such as outweigh the many and important considerations which favor the higher frequency, requires more complete data than we have been able to secure up to the present time. That the difference is material, however, is established not only by general theoretical consideration of the effect of a reduction in frequency upon the design and performance of single-phase commutating motors, but also by the following facts:

1. In the case of multiple-unit equipment of passenger cars where locomotives are dispensed with and motors carried upon the car trucks, it is very important that the dimensions of motors be reduced to a minimum. Cars weighing, say, 35 tons without equipment and operating on straight and level track at speeds of from 60 to 70 miles an hour, require but two motors, except as it may become necessary to employ four motors by reason of lack of sufficient clearance at cross-overs. The difference between a two-motor equipment and a four-motor equipment in such a case approximates $2,500.00 per car, besides which the four-motor equipment adds materially to weight, practically doubles complication, and, for both of these reasons, increases cost of operation. The difference between the dimensions of a 15-cycle and a 25-cycle motor may easily be the controlling consideration compelling the adoption of the four-motor equipment.

2. In the application of single-phase commutating motors to locomotives in general railway service, the minimizing of motor dimensions is perhaps still more important, although in this instance the limitations imposed by the space available are less obvious.

High-speed passenger locomotives at least should be gearless. For any assumed limits of weight per axle and length of wheel-base, that frequency is preferable which permits the construction of a motor which will exert the greater pull at the draw-bar, provided efficiency, commutation, and power-factors are substantially equal.

Those who are engaged directly in the design of single-phase motors are probably in position to contribute to the discussion of this paper data which will throw much light upon the subject; but it would seem probable that within given limits of dimensions, 15-cycle motors would materially surpass 25-cycle equipment in this respect. We are inclined to this opinion notwithstanding the probable advantage of 25-cycle equipment as regards the ratio of effective draw-bar pull to weight upon drivers.

3. There can be no question of the superiority of the 15-cycle motor in respect to the very important features, commutation, efficiency, and power-factor. Efficiency is obviously and directly important. Power-factor affects the efficiency of the

entire system from the motor to, and including, the generator. Commutation, in view of the large and expensive commutators and the brush complication of this type of motor, is of great importance.

In order that the question raised may be looked at in proper perspective the following estimates based upon foregoing calculations will be useful:

For the equipment of the entire railway system of the United States as now existing an aggregate power-house output capable of supplying continuously 2,100,000 kilowatts would be required. Of the electric apparatus installed in the power-houses, a change in frequency affects the generators, transformers, and a large proportion of the measuring and indicating instruments. It also affects the cost of the engine or turbine employed to drive the generator. At 25 cycles, the apparatus affected by frequency should cost approximately $30 per kilowatt. At 15 cycles it would cost on the average perhaps $33 per kilowatt. Cost of sub-station transformers would be increased approximately one-third, and, in round numbers, the total cost of turbines and electrical power house and sub-station apparatus would be increased from $70,000,000 to $80,000,000.

If it be assumed that one electric locomotive will do the work of two steam locomotives, about 24,000 electric locomotives would be required to take care of the present railway business of the country. Assuming the cost of the average electric locomotive to be $25,000 the aggregate cost of locomotives required would be $600,000,000. Allowing for the increased cost of the 15-cycle transformers, it would seem that the difference in cost of the average locomotive should be not less than $1,000 in favor of the lower frequency, or for 24,000 locomotives $24,000,000. This is more than twice the estimated difference in cost of power-house and sub-station equipment.

It seems entirely safe to say, therefore, that the aggregate first cost of electric equipment and of steam turbine will be decreased by a change from 25 cycles to 15 cycles. The operating cost will obviously be decreased very materially. At least three-fourths of the above estimated cost of electric locomotives, say $450,000,000 represents cost of electric equipment. It will be seen, therefore, that of the apparatus which our electrical manufacuring companies may be called upon to furnish, more than 85% is rolling stock. Obviously, any argument in favor of 25-cycle equipment which may rest upon existence of drawings and patterns and convenience in manufacturing should have comparatively little weight.

The use of 15 cycles instead of 25 cycles also secures considerable advantage in respect to the overhead trolley conductor and track return. With a given limit of voltage-drop, this advantage may be utilized by reducing size and, consequently, cost of the overhead copper and the copper used to reinforce the track return.

Under the plans which we have assumed as a basis of our calculations, the amount of copper required for feeder circuits, trolleys, and reinforced track-return, estimated at 20 cents per pound would cost approximately $750,000,000 were the entire railway system of the country as existing in 1905 to be equipped for electric operation.*

We desire to acknowledge with appreciation, assistance kindly rendered in the collection of data for this paper by Mr. J. M. Graham, vice-president of the Erie Railroad Company; Mr. Theo. N. Ely, chief of motive power of the Pennsylvania Railroad Company; Mr. George Gould, president of the Missouri Pacific and other railway systems; Mr. E. Z. Jeffrey, president of the Denver & Rio Grande Railroad Co.; Mr. E. P. Bryan, vice-president and Mr. Frank Hedley, general manager, of the Interborough Rapid Transit Company; Mr. G. Leve, of the Railway Electric Power Company; Mr. Alvan Markle, president of the Wilkes-Barre & Hazleton Railway Company; Mr. George C. Smith, vice-president of the Security Investment Company; Mr. H.J. Pierce, president of the International Railway Company; Messrs. Conwell, Shepard and McLaren, of the Westinghouse Electric & Manufacturing Company; and Messrs. Potter and Mahony, of the General Electric Company.

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*In all our estimates we have included 0000 copper conductor in the return circuit, this being bonded to the rails at intervals for the purpose of preventing dangerous potential on track in case of a broken bond.

APPENDIX

Power-House Output and Load-Factor

The report of the Interstate Commerce Commission gives the total revenue traffic for the entire United States for the year ending June 30, 1905, as 1,038,441, 430 train-miles, of which 459,827,029 is passenger-train mileage, 546,424,405 freight-train mileage, and the unclassified balance, 32,189,996, we have assumed to be mail- and express-train mileage. Including the mail and express trains with the passenger-train service, there is an average of 6.2 passenger and 6.9 freight trains per mile of line per day, or approximately 7 trains each way per day.

Using average weights of equipments, as stated in our paper, and average hauls of goods and passengers, and making allowances for switching, etc., the traffic amounts to 3,000,000 ton-miles per mile of line per annum, of which 600,000 ton-miles are in passenger service and 2,400,000 ton-miles in freight service. In electric operation these figures will be reduced by the weight of engine tenders and a part of the weights on pony trucks.

To supply electric power for the operation of the steam roads, we have assumed that power houses would be located at average intervals of 300 miles. This requires a transmission of 150 miles and for this purpose we have employed in our calculations 60,000 volts. As stated in our paper, both the distance of transmission and the voltage employed are within current practice in plants now in commercial operation in this country, under conditions and for purposes identical with those contemplated in our paper.

In our calculations we have assumed that passenger trains are geared for a maximum speed of 50 miles per hour and freight trains 25 miles per hour, on a tangent and level track. We have assumed that the average run of passenger trains is 10 miles and freight trains 15 miles between stops. With the gear ratios used this gives an average speed of 40.5 and 23 miles per hour, respectively. At these speeds the average load on each power station supplying 300 miles of line is 1.98 passenger trains and 3.84 freight trains, an average of 5.82 trains of both kinds. With equal intervals between passenger and freight trains, respectively, the average load on the power house is 2100 kw., the load-factor is 0.97 and the maximum momentary peak is estimated to be 3000 kw. This method of operation is shown in Fig. 9.

The schedule speeds above mentioned include momentary stops only. As trains are now operated, the average passenger train, owing to stops and delays of various kinds, does not average more than 30 miles an hour, and through and local freight trains probably do not average more than 12 miles an hour. In Fig. 10 we have illustrated the result at the power house if trains are operated at these modified average speeds. The average load remains practically the same as before, while the load-factor is reduced to 0.82 and the estimated maximum momentary peak is increased to 4700 kw.

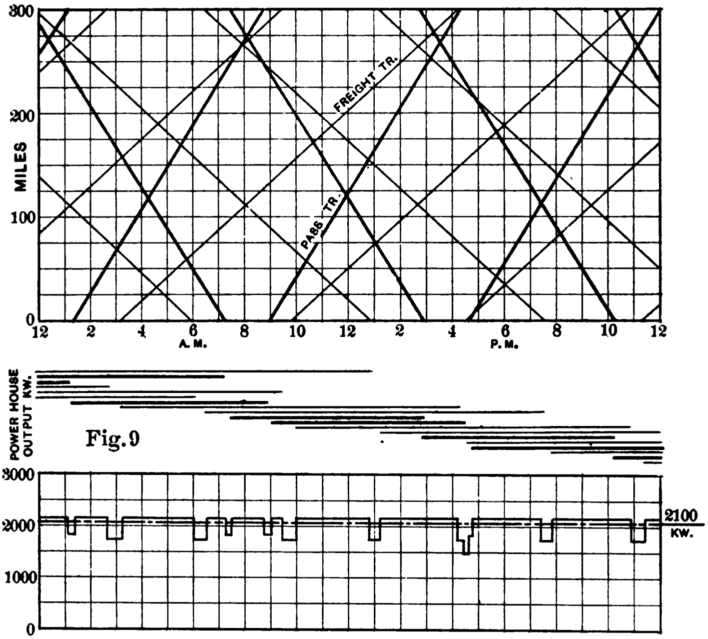

Fig. 9.—Power-House Load, Maximum Average Speeds.
Passenger trains, 226 tons, 40·5 miles per hr. 273 kw.
Freight trains, 937 tons, 23.0 miles per hr. 351 kw.
Transmission efficiency 90%. Average trains on section, 5.8.
Average power house load 2100 kw. Load-factor 0.968.
Estimated momentary peak 2970 kw., 85% efficiency.

Our estimate of the total power-house capacity for all the railroads of the United States is 2,100,000 kw., which is approximately 3,000 kw. for each 300-mile section. This is nearly 50% in excess of the average load. The generators proposed for this power-house equipment have a momentary overload output of

100% and can carry an overload of 50% for several hours. It is evident, therefore, that the average power plant provided, after deducting 20% for reserve, is ample to take care of ordinary variations in traffic.

It is manifestly impossible for railroads to operate their passenger and freight trains on equal headway. Some roads as a matter of convenience despatch freight trains in " fleets ", and cattle and some produce trains must arrive at their destinations at fixed times of the day. This method of operation is desirable and practicable in steam operation and obviously is objectionable in electric operation, as power-house capacity must be provided for the maximum number of trains on the division. On the other hand, on those roads where traffic is most congested, the track facilities can best be utilized by equal spacing of trains. When this question becomes important, therefore, the natural tendency

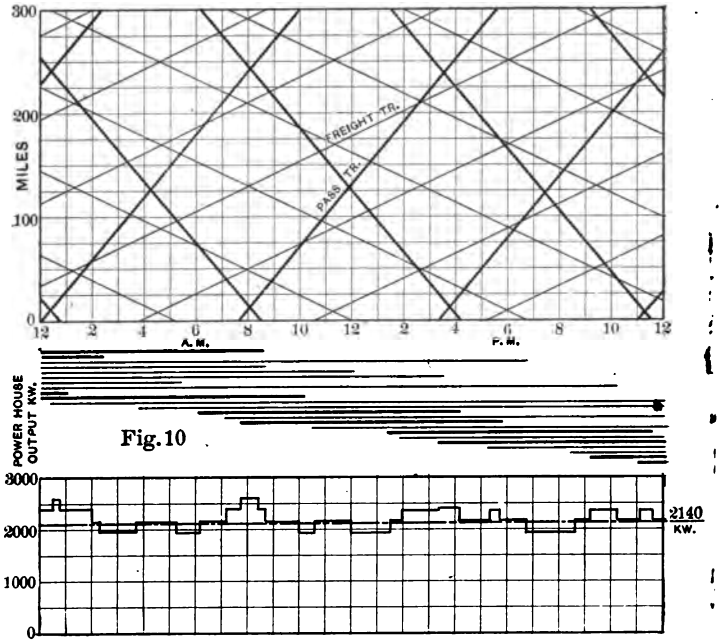

Fig.10

FIG. 10.—POWER-HOUSE' LOAD, MINIMUM AVERAGE SPEEDS.
Passenger trains, 226 tons, 30 miles per hr. 210 kw.
Freight trains, 937 tons, 12 miles per hr. 187 kw.
Transmission efficiency, 90 %. Average trains on section 10.0.
Average power-house load 2140 kw. Load factor 0.823.
Estimated momentary peak 4720 kw. 85% efficiency.

is towards an approximately equal distribution. As the generators include in our estimates have a continuous overload capacity of 25%, 50% for several hours, and 100% momentarily, and as we have provided an excess of nearly 50% over average demands, the power-house capacity provided appears ample for any reasonable variation in the method of operating trains. In this connection, we wish to call attention to the fact that under average conditions freight trains require 25 hours to traverse the length of line supplied from a single power house; hence if trains are despatched in " fleets " a second fleet will begin to draw upon the power house as the first fleet passes off the power-house load remaining practically constant.

RESISTANCE DUE TO GRADES

In many cases we have found so far as power house-requirements are concerned that the additional resistance, due to grades and curves, can be practically neglected in the electric operation of trains. Unlike the steam locomotive, the electric motor, under certain conditions, operates at higher efficiency on grades and curves than when running free on a straight and level track. This is due to the fact that the motor and gear ratio are properly selected to obtain the highest average efficiency in operation. The effect of this selection throws the load in continuous operation on level track below the point of maximum efficiency. In ascending a grade the speed is reduced, and within reasonable limits this reduction implies an increase in motor efficiency. Again, the reduction in speed, due to grade, results in a reduction in rolling friction and train resistance. These gains are not offset in descending grades unless, in addition to gravity, power be used to attain a speed exceeding the maximum limit which we have assumed, namely, 50 miles an hour in passenger service and 25 miles an hour in freight service. Theoretically, as long as the grade does not introduce a resistance in excess of that of the train-friction independent of the grade, the energy expended in lifting the train will be recovered in overcoming train-friction in going down grade. If the ascending and descending speeds are equal the energy consumption will be the same per ton-mile as on a straight and level track of the same length. If the ascending speed is reduced, as it is in the case of the series motor, the total watt-hour consumption will also be reduced. In Fig. 11 and Fig. 12 we have plotted the effect of grades upon power consumption in both passenger and freight service. In order to keep this discussion distinct from the question of motor and transmission efficiencies, we have assumed a motor efficiency of 85% in all cases and 90% transmission efficiency. All power calculations are carried back to the power house, and that portion of the recuperated energy which cannot be utilized by the train auxiliaries has been returned to the power house at 90% efficiency. Extra electric locomotives are added as needed. With the train weights employed, it will be noted from an inspection of these curves that the power consumption over grades is less than it is over straight and level track in passenger service for all grades less than 0.55%, and in freight service less than 0.35%. Comparatively few lines are absolutely level, but on the other hand the aggregate mileage on grades exceeding 0.5% is relatively small. It is believed, therefore, that the general result as to power consumption will be very close to that required over straight and level track. Nevertheless, as stated in our

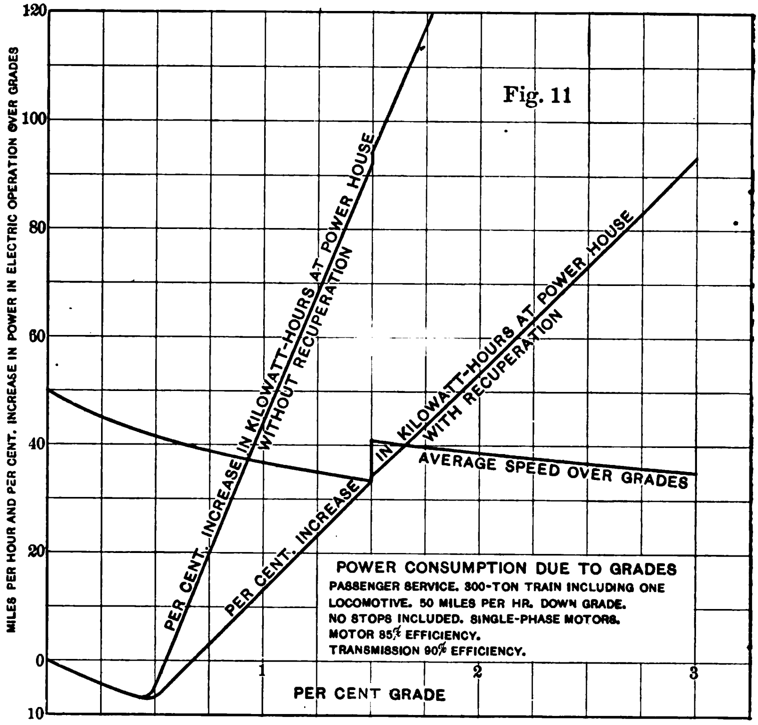

FIG. 11.

paper, we have added to our calculations of energy required 10% in the case of passenger service, and 15% in case of freight service, to cover contingencies, including switching, "double headers" and the additional resistance due to grades and curves.

In some recent calculations in which we went into the subject in great detail the foregoing conclusions were corroborated. In one case in express service the detailed calculations of runs over the road showed a consumption of power of 53 watt-hours per ton-mile, while 52.8 watt-hours per ton-mile was obtained by using an average run on a straight and level track. In the local

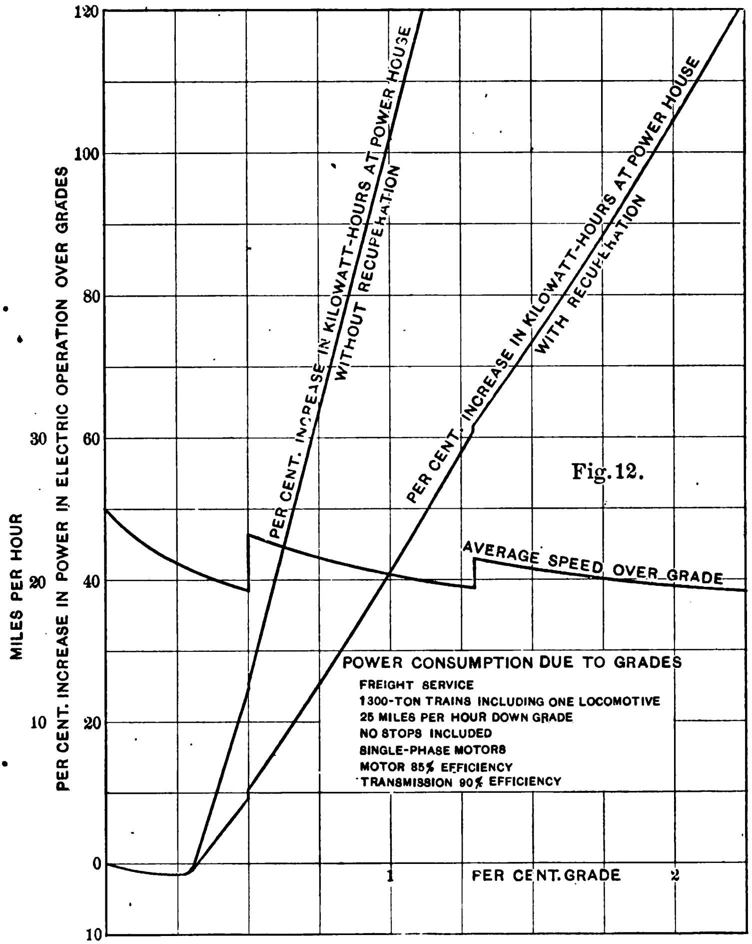

FIG. 12.

service over the same line the figures were 84.2 watt-hours in the detailed calculations and 86 watt-hours for an average run on a straight and level track. These results were obtained from calculations relative to the electrification of the suburban portion of a steam railroad over 30 miles in length; a large percentage of its tracks being on grades and curves. There were maximum grades of 1.47%, 1.55%, and 2.32% and curves of 6° 22′ and 8° 30′. Numerous other calculations and road tests have verified these results.

RECUPERATION.

In making our calculations as to power consumption, we have made no deduction for the electrical return of power to the line. In the case of the higher grades this becomes a matter of importance, as shown by Fig. 11 and Fig. 12. Where the force of gravity due to grade exceeds the amount that can be utilized mechanically in overcoming train-friction, recuperation reduces the increase in power consumption due to the grade by approximately 60% over a grade of 1.5%, so that even in freight service over mountain grades the power required will not exceed that consumed on a level track by more than from 40% to 60%. With recuperation, the power consumption or what is its equivalent, the coal consumption, is not doubled until we reach grades of over 3% in passenger service and 2% in freight service. These grades are considerably in excess of any used on our trunk-line railroads. The ability to recuperate energy is important on lines that have heavy grades. In addition to the saving in power, the saving in wear and tear from mechanical breaking is of as great, and perhaps even greater, importance. The energy represented by the difference between the curves shown on Fig. 11 and Fig. 12 representing the power required at the power house with and without recuperation, increased by the energy losses absorbed by the motor and transmission lines, must be absorbed by the brake-shoes and wheels when mechanical braking is used.

DISCUSSION ON "ON THE SUBSTITUTION OF THE ELECTRIC MOTOR FOR THE STEAM LOCOMOTIVE," AT NEW YORK, JANUARY 25, 1907.

(Subject to final revision for the Transactions.)

Frank J. Sprague: This paper has evidently been prepared with a good deal of care, but in certain essentials I am absolutely at variance with some of the conclusions which have been expressed. There is so much to be said, and the time is so limited, that it would be discourteous to the authors and an injustice to myself to attempt to enter into detailed comment, so I shall content myself for the present with only a few remarks.

Briefly, the authors have given an interesting resume of statistical information based almost entirely upon direct-current operation in this country, with some report of results from operation on the three-phase system abroad under conditions differing largely from those characterizing American railroads. They have generalized the features of operation of the steam railroads of the United States, and on that generalization have formulated certain conclusions favorable to the adoption of electricity. All these should receive careful attention and analysis. In addition, they plead for standardization of electric apparatus and equipment, and, if I understand correctly, for a standard of operation based upon the use of single-phase alternating-current motors operated at 11,000 volts and 15 cycles from an overhead trolley.

Their attitude, as expressed in their paper, is emphasized by these two statements:

> The distributing system for altenating-current equipment, which is the only class of equipment deserving serious consideration in connection with the general problem which we are discussing, comprises an addition to permanent way equipment in the form of overhead construction, and electric conductors conveying power from the power house to the trolley or conductor which is carried above the track.
>
> The advantage in favor of electric operation is of course more marked if we assume that alternating-current equipment is to be used, as in general would be the case in the electrification of trunk lines or long divisions.

These are certainly positive affirmations, and if sound would perhaps warrant that spirit of enthusiastic and inquiring prophecy in which the sound basic principles which have made electric traction successful are coupled with various unscientific and quickly discarded proposals, and lightly brushed aside with the query:

> Where, ten years from to-day, will be the 1200-volt or 1500-volt direct-current systems which have been suggested as substitutes for high-potential altenating-current systems in heavy electric traction?

I think I see my initials under these specific voltages; and it is right here that I beg to differ from the conclusions expressed by the authors, and venture to correct them. The higher-potential direct-current systems will still be here, just as we have the lower voltages of the past 19 years, no matter what other developments may take place.

I have been guilty, gentlemen, of some "fads and fancies" while a member of this Institute for a time covering the entire practical development of the electric railway, in which I have played some material part; they have been translated into facts. I have ventured a few prophecies; they are now a part of history.

Operation at 1200 to 1500 volts by direct current has not been advanced by me as a "substitute" for high-pressure alternating currents for heavy electric traction, or as the only means available for this purpose; it has been advocated as one practical development along existing lines which under many conditions, and with the present development of the 25-cycle alternating-current motor, offered some possibilities of railroad operation denied to the latter.

I prefer to define my own position rather than to have it determined for me by others. I do not profess to know what the ultimate developments in this art are going to be, nor will I enter into any rivalry in predicting that a specific type of equipment must be universally adopted, for I feel sure that the selection of a system by any road must be largely individual, and determined by its own necessities.

There will be opportunities for alternating-current equipment, and there are many hopeful alternating-current possibilities, but surely these are not the only practicable methods worthy of serious consideration by such trunk-line divisions as may reasonably consider the possibilities of electric operation to-day.

As useful as a mass of statistics may be, I do not think it necessary, to come to specific conclusions in the matter of electric railway equipment, to generalize all the railroads of the United States. There are a lot of them in the hands of receivers, and some of the others ought to be. They could not be taken out of their hands if they were electrified, and could not raise the money to be electrified if they wanted to. I prefer to deal with the living, immediate questions. There will in the near future be three great trunk-line railroads terminating in New York City, to say nothing of those terminating in Jersey City and elsewhere, on which the question of electric operation is assuming special importance. One of them is proceeding along certain lines, another by somewhat different methods. There has been considerable discussion as to the wisdom of both. I have been guilty of some of the development on one, and I am not ashamed of it. I have somewhat frankly criticized some matters connected with the other, and I have no apologies to offer on that account. But leaving these two roads out of consideration, do we need to look further for a typical trunk-line division than to the third road, the Pennsylvania, from here to Philadelphia? An engine run, and none more typical. I am going to venture, not a prophecy, but a statement. If that line were called upon to be electrified to-day—and it can very properly and seriously consider it—it would not, in my present judgment, be best done by a single-phase overhead trolley alternating-current equipment, whether 25 cycles, 15 cycles, or 1 cycle. There would be a variable half cycle, and it would be the length of time between controller operations. And on many other lines which can properly consider electrification, the higher voltage direct-current system, according to any present development, will give better results than the alternating-current overhead system.

These conclusions are based in part upon a four months' study and analysis of one of the most difficult railroad problems in this country. Had I not been closely occupied in trying to complete that particular investigation, I should be in a better position more fully to discuss the paper of the evening. I hope, however, in the comparatively near future to present to this Institute, of which I have had the honor to be a President, a few comparative statements on the subject of direct-current and alternating-current operation, and I will reserve until that time most of what I have to say.

B. G. Lamme: As the time is limited, I shall confine myself to the question of frequency alone. It may be of interest to consider the changes in frequency from the earliest time to the present, and see what Mr. Stillwell has had to do with such changes. Back in the early times of alternating-current, work, 133 cycles per second was the common frequency. About 1889 or 1890, Mr. Stillwell, in going over the problem, saw that the larger work which was coming called for a lower frequency, and he was one of the strongest advocates in adopting 60 cycles as against 133. A few years later, in connection with the Niagara Falls first large generating station, the question of a still lower frequency came in, and Mr. Stillwell practically made the decision in favor of 25 cycles. At that time it was considered that the development of street railway work, and the use of synchronous converters in such work, was such that it was more economical to use the lower frequency. He now comes forward with 15 cycles for heavy railway work on the basis that the field is going to be large enough to call for a new and more suitable frequency.

It seems to me also, considering the total amount involved in the electrification of the railroads of this country, about $1,500,000,000, that the problem is big enough to call for a frequency which is best suited for the work. The question is whether that should be 25 cycles or something lower. Over four years ago I presented a paper before this Institute, in which I described the Washington, Baltimore and Annapolis single-phase railway, and the frequency given was 16⅔ cycles, a ratio of 2 to 3 to the standard frequency of 25. There were certain reasons for adopting that particular frequency, although 10 per cent. higher or lower would not have been of very great importance as far as the operation of the apparatus was concerned. It was found at the time that there was considerable opposition to the use of lower frequency, principally because most of the projects presented involved existing power plants, or it was necessary to tie the new plant to existing power plants. The projects were also relatively small. Because of commerical conditions, we were practically forced to begin at 25 cycles. However, I still advocated the use of lower frequency when it came to heavier work, as will be found in my discussion of single-phase railway apparatus at the Institute meeting at St. Louis Exposition in September 1904. At that time I said that I considered the heavy railway electrification of sufficient importance to warrant the use of a low frequency which is most suitable for such work, independently of any frequencies already in use. I still hold to that opinion.

The strongest reason which can be given for the lower frequency is the greater output that can be got from a given motor. For instance, with a first-class motor, built for 25 cycles, the operation may be above question, the machine may be considered perfect in every way; but take that same machine and operate it on 15 cycles, and the induction can be raised from 25 to 40 per cent., which means that 25 to 40 per cent. higher voltage can be applied with the same motor-speed, and 25 to 40 per cent. greater output is obtained from the same motor, or 25 to 40 per cent. greater tractive effort can be developed. That in itself is a controlling feature in the question. We have verified it by actual test. For instance, we have taken a 100-h.p., 25-cycle motor, and obtained from it 125 h.p. at 15 cycles. This motor has good efficiency, good power-factor, and good commutation on both frequencies, at the above ratings. It is therefore not a question whether the 25-cycle motor will work, for it will work successfully, but it is a question how much more can be got out of it by going to the lower frequency. It may be questioned that if 15 cycles is better than 25 cycles, why is not a still lower frequency recommended? The answer is that at 15 cycles the machine is practically saturated, which fixes the output. At still lower frequency there would be a gain in efficiency and power-factor, but not much in output; and there would be loss in other things, such as the speed of turbo-generators and weight of transformers. So there is some point at which a compromise can be made; and it is my opinion, and has been for a long time, that this compromise is considerably below 25 cycles and should be about 15 cycles.

The increased output to be got from a motor at the lower frequency is of advantage principally in getting a smaller number of motors under a locomotive or car, which directly decreases the cost; or, on a locomotive, keeping the same number of motors, there is obtained a bigger output for a given weight of locomotive. But there are some cases where not much is gained by the use of lower frequency; for instance, where it is necessary to operate alternating current-direct current requiring four motors in order to obtain series-parallel control. In most cases we do not get the full gain from the use of 15 cycles for we can not reduce the number of motors. That is one of the conditions met in the New Haven railway equipment, for the direct-current operation on the New York end requires the use of four motors. There are many cases where the power is purchased in which it is necessary to use the higher frequency. Of course, the results are obtained at a somewhat lesser capacity or at increased cost.

There is one point Mr. Stillwell has not touched on, and that is the fact that the single-phase series motor can be made to operate on both 15 and 25 cycles; for instance, a 25-cycle motor will operate beautifully at 15 cycles and at practically the same speed, because the speed has nothing to do with the frequency. A 15-cycle motor, if well designed, will operate on 25 cycles fairly well, at its nominal capacity; at a slightly reduced capacity it will operate very well, so that if a locomotive should be equipped with transformers suitable for operating at 15 cycles. for instance, it could operate on both 25 or 15 cycles. By taking a 25-cycle equipment, nominally designed for 25 cycles, and putting a 15-cycle transformer on it, the equipment is adapted for operation on both 25 and 15 cycles. That is important in connection with the fact that 25 cycles will have to be used in a certain number of cases, but in other cases where the generating conditions can be made suitable, 15 cycles will work to better advantage.

Mr. Stillwell speaks of some of the advantages of the higher frequency, one of which is the better ratio of tractive effort to weight on drivers. We have been making tests at East Pittsburg on some electrical locomotives, at both 15 and 25 cycles, and it is very difficult to determine any difference in the ratio of tractive effort to the weight on the drivers. In some cases the tests are possibly in favor of 15 cycles, in others in favor of 25 cycles; and the difference is probably no more than would be found in making two consecutive tests at any one frequency. If the motors are spring-connected, or have some flexibility between the armature and the driver, which is true in most cases, especially where they are geared, the difference in the tendency to slip practically disappears.

In discussing this question of 15 cycles, we are asked—where is it in use? I will call attention to the fact that quite a number of European companies have adopted 15 cycles for railway work. The Valtellina, plant put in by the Ganz Company, with three-phase motors, uses 15 cycles; and I feel safe in saying that a great deal of the success and good operation of that plant is due to the choice of this frequency. I think they could have made the apparatus a success with 25 cycles, but it would have required much heavier equipment, and with poorer efficiency and power-factor, especially at low speeds. The manufacturers recognized that 15 cycles gave better conditions with the polyphase motors, and adopted it regardless of the fact that that was not a standard frequency in Europe. That system is being extended on the Italian roads.

The Oerlikon Company, of Switzerland, has gone into the single-phase work extensively, with 15 cycles as a standard. The Siemens-Schuckert Company, of Germany, is also manufacturing series railway motors for 15 cycles. The Allgemeine Company, of Berlin, is the principal company which is adhering to 25 cycles, and that is largely due to their type of motor. They have a so-called " series repulsion " motor, in which the characteristics of the motor apparently show to better advantage if the frequency is not too low. It is not directly due to the high frequency that they get better results, but to the fact that the motor should preferably run below the nominal synchronous speed, and this condition is obtained to better advantage by keeping up the frequency.

Bion J. Arnold: On the morning of December 18, 1903, when I arrived in New York from Pittsburg, where I had been examining Mr. Lamme's new single-phase motor and complimenting him on its work. I received a telegram saying that the single-phase locomotive which I had been developing for three years past, and which was at that time ready to make its trial run, had been destroyed by fire. While experimental runs had been made some months before with a rather crude machine, I had everything arranged to make the trial run on the first day of January, 1904, with a new electropneumatic motor which I had developed, and by means of which I expected to demonstrate a single-phase railway in operation. I did not then discover, nor have I yet discovered, the cause of the fire, but it burned up the machine. I felt that unless the machine were rebuilt and an attempt made to operate it, I might be misunderstood by those not familiar with the circumstances. I therefore rebuilt the machine and operated it on August 3, 1904, in time to antedate my competitor in this country by some days. That experiment cost me about $50,000, but thanks to good fortune it cost no other man a dollar.

I believe that by this experiment I was instrumental in advancing the state of the art to such an extent that to-day two or three of our large railroads are being equipped with the single-phase system, invented by others, to be sure, but I believe forwarded by my efforts of some four or five years ago. If my efforts have done that, and I have been instrumental in advancing the art, I am glad I spent the money, as I could not have spent it in any better cause.

I shall not attempt to go into a detailed analysis of the various systems which are involved in the paper, because I think each system has its able champions. It makes no great difference to me personally which system wins, so long as we get a system of electric railroading in this country that will operate the trains for less than it now costs to operate them by steam. I had that idea in mind in starting out on the single-phase experiment, because in 1898 I was engaged in building the Chicago and Milwaukee electric railway, which I believe is considered the pioneer synchronous converter sub-station railroad in the country, possibly in the world; at any rate, the first to be driven by a steam station. I took much risk in that undertaking, risking my personal reputation and my financial resources, in order to demonstrate the success of that enterprise. It was a success, and as you know most of the suburban roads have since been built on those lines.

I make no claim for the invention of many of the devices which entered into the systems. They were invented by some of the gentlemen here present, and by others, and some had just begun to come into commercial use; namely the synchronous converter, which made the system possible; but I took the risk of putting into practice such a system, took the engineering and financial responsibilities, of making it go. It went. When engaged in that work I felt that that system was not the complete solution of the electric railway problem, because the introduction of the synchronous converter sub-station necessitated men in the sub-stations, and necessitated more investment than I thought the railroad systems of the country could stand, if they were to be attracted to electrical operation. That started me on the single-phase idea, and as many of you will recollect, we had various discussions on the subject, and it was stated by some of those here present who are now advocating the system, that it could not be done. I maintained it could be done, and had to be done, and it cost me much to find that out. It has been done since by at least two companies in this country, and two or three abroad, and seems to be coming quite rapidly into practice for steam railroad work.

I do not agree entirely with the authors in regard to standardizing this apparatus, as this would shut out the utilization of the talent of the members of this Institute and other societies in this country, and other countries, and the prospect of developing something that may prove better than anything we have now. I am willing to concede, if we are going to use alternating-current railway systems, that we should adopt a standard frequency. So far as my investigation has gone, in conjunction with Mr. Stillwell as a member of the electric traction commission of the Erie railroad, my leaning is toward the 15-cycle frequency. Although I do not want definitely to stand on that conclusion now, I think it is the frequency we will come to on account of the fact that to get the requisite amount of capacity between the wheels of a railroad-car truck, the gauge being limited, it is necessary to get as much power in the space as possible. This can be done by adopting 15-cycle motors, as these motors are more powerful than 25-cycle motors of equal size. It makes the total weight of the locomotive or car practically the same as at 25 cycles, as it increases the size of the transformer. Even then we do not get as much power on the wheels with the alternating-current motor as with the direct-current motor.

I personally believe that some form of high-potential overhead conductor is going to be the final solution of the railroad electrification problem. I believe in the third-rail, where it is applicable, but I do not believe there are many places where it is applicable; in other words, I think that legislation in this country will prohibit the use of the third-rail in exposed places. There are certain types of third-rail which have recently been adopted, which I believe are safer than previous third-rails; I refer to the rail that was devised by Messrs. Wilgus and Sprague and used in the New York Central installation—but I do not think that the use of the third-rail in yards, and under the feet of men, and in other exposed places, will be accepted as the final solution of the problem. In the analysis of the Grand Trunk problem, which I have in charge so far as the engineering decisions are concerned, I chose the alternating-current system, overhead conductor, for tunnel work principally, for the reason that in the large yards at each end of the tunnel, where much switching is done, it seemed essential that the conductor be kept from under the feet of the men. The decision to use the single-phase motor was made some five months prior to the decision by the officials of the New Haven Company to adopt the alternating-current system on their road. The officials of the Grand Trunk did not publish their decision, as certain matters had to go abroad for approval by the English officials before the matter could be publicly announced, but there are men in this room who know that the decision was made at that time.

W. B. Potter: I heartily endorse the recommendation of the authors of this paper as to the desirability of making an effort toward standardizing the essential principles which are involved in the determination of electric railroad problems. To this general proposition may well be added the plea for a uniformity of dimension for such parts of the equipment or general system as might reasonably be made interchangeable.

Considering the matter of standardization in its broader aspect, there does not appear to be any one general system of electrification, in the present state of the art, which engineers would be willing or ought to accept as the standard. For the ordinary city or interurban trolley lines, 600 volts direct current is to-day recognized as a standard. For other classes of work, particularly over long-distance lines with relatively infrequent headway, both the single-phase alternating and the high-voltage direct-current systems possess advantages. The fundamental reasons, however, which have lead to the consideration of a higher voltage trolley may also apply to limit the application of the high-voltage trolley under conditions which can be more economically met by 600-volt apparatus. However much we may desire to limit the number of standard systems we must still recognize that the element of cost, considered broadly, is often the determining factor to be reckoned with. A railroad company could hardly be expected to consider favorably any particular system simply because of general reasons, if the installation of this system involved any considerable additional expenditure on their part.

The matter under discussion this evening, however, relates more particularly to the consideration of the single-phase alternating system than a discussion of the general subject. Of all the apparatus used in the electrification of a railroad, the motor is in particular that part of the equipment which is limited in dimension by the height of the car-body, the clearance over the rails, the width between wheels, and the wheel-base of the trucks. By reason of these limitations, and considering further the proportion of cost which the motors bear to the general expense of electrification, any condition which diminishes the capacity of a motor of given size may very well become subordinate to the motors themselves.

The output of a single-phase motor, particularly its tractive power in the larger sizes, may be limited by the permissible commutation, and as commutation is improved with reduced frequency the suggestion of 15 cycles instead of 25 cycles is worthy of serious consideration. The field of application for the single-phase motor, particularly in the larger sizes which are required for locomotives and heavy railroad operation, will unquestionably be greater if the motors are operated at a lower frequency than 25 cycles.

Compared with a direct-current motor, a 25-cycle motor of corresponding service capacity would weigh approximately 25% more; while at 15 cycles, the single-phase motor would weigh probably not more than 10% in excess of the direct-current motor. The efficiency and power-factor of the single-phase motor on either 25 or 15 cycles would be approximately the same. While the motors and the reactance of line and track are benefited by a lower frequency, there is the increased cost of the generators and transformers to be taken into account.

Messrs. Stillwell and Lamme have both spoken of the effect of a lower frequency upon the maximum available tractive effort. You will appreciate that owing to the characteristics of an alternating current, the average tractive effort of the single-phase motor is approximately 50% of the maximum at the top of the current wave, and with a motor rigidly mounted the wheels would begin to slip at about one half the tractive effort which would be given by a direct-current motor under the same conditions of track and weight on drivers. With the motor mounted on springs in the usual manner, there is introduced some degree of flexibility, and the impulse due to the top of the wave is absorbed by the springs so that the average torque is considerably higher than the theoretical 50%. Under similar conditions of track, with equal weight on drivers and the same method of mounting, tests have been made which indicate that in comparison with the same motor on direct current, the maximum available tractive effort at 25 cycles is from 80% to 90%, and on 15 cycles from 70% to 80%. The maximum available tractive effort is not generally important except in locomotive operation where the maximum draw-bar pull is in a sense the measure of the locomotive's value for starting a train, and during acceleration. On motor cars there is usually an excess of weight on the drivers over that required for acceleration, so that the maximum tractive effort is a matter of less importance.

It is, incidentally, an interesting fact that after the wheels have commenced slipping the direct-current motor shows a much greater reduction in tractive effort than the single-phase motor. The torque being maintained uniformly with a direct-current motor, the wheels rotate rapidly, reducing the coefficient of friction with the rail to something like 20% or 30% of the maximum adhesion. With the alternating-current motor, both on 25 and 15 cycles, although the initial slip is at a lower maximum, the draw-bar pull is only reduced to 80% or 90% of the maximum adhesion. This appears to be due to the fluctuating character of the torque, which at its minimum allows the wheel to secure a slight grip on the rail after the wheel begins to slip. When the wheel is slipping its rotation is not uniform but fluctuates, corresponding with the frequency. While of interest, this higher tractive effort, after the wheels commence to slip, is of little practical value.

Mr. Sprague has referred to higher voltage direct-current motors. With respect to motors suitable for operation on higher voltage direct current and also on 600 volts, I would mention the marked improvement in the motor that has been obtained by the addition of a commutating pole. As an illustration, a motor having commutating poles and designed for operation on 600 volts, can be run at full load on 1000 volts so far as commutation is concerned, and further, such a motor, when the current is momentarily interrupted or there is a momentary rise in voltage, will not flash over, as sometimes happens with motors not having commutating poles. A commutating-pole motor designed for 1200 volts and operated at that potential would be superior to the ordinary 600-volt motor, both with respect to commutation and liability to flash over. I feel that the addition of the commutating pole to the direct-current railway motor, in its effect on commutation, is comparable to the improvement made by the substitution of the carbon brush in place of the copper brush. The carbon brush reduced the sparking and flashing to a permissible degree, and the commutating pole by neutralizing the cause has finally eliminated defective commutation.

A word with regard to the much maligned third-rail. I feel that there is much to be said in its favor. We have not as yet had an equal opportunity to pass judgment on the heavy overhead construction, and I would suggest that we await developments before expressing our opinion too positively with regard to either system of conductors. Both the third-rail and the overhead conductor have a proper field in heavy railroad application; they should be so regarded, and neither of them condemned in the light of our present knowledge.

W. S. Murray: During the year and a half that I have been associated with the New Haven road I have been able to make some rather interesting experiments with steam locomotives, of the freight and passenger types. I thought they might be of interest, particularly in view of Mr. Stillwell's reference to Item 12 of the paper, which relates to "Repairs and Renewals of Locomotives." I understand that this item, for the Valtellina line, represents a figure of 1.8 cents per locomotive-mile. That is a figure I have been very anxious, indeed, to obtain. I have here some accurate figures on the cost of steam locomotive repairs extending over a period of exactly one year, in which ten freight and ten passenger engines were involved. I think you will all be surprised to note what these figures are. I have divided the cost of repairs into two parts; one on the basis of maintenance, the other for purely mechanical or shop repairs, each including labor and material. I have included in the maintenance the following heads: Cost of oil and waste, flues cleaned, ash-pan and grates cleaned, engines wiped, engines turned, engines fired, boilers washed, and the cost of sand. Of course, some of these figures will be matched in electric operation, but to get the actual figure I have included them all.

The record is as follows:

For passenger locomotives: maintenance \$0.0172; shop repairs \$0.0388; total repairs per locomotive-mile \$0.056.

For freight locomotives: maintenance \$0.0142; shop repairs \$0.0668; total repairs per locomotive-mile \$0.081. I believe that these figures give a definite idea of the saving to be effected by the electric method of train propulsion.

I think the most interesting feature of the paper is in regard to the matter of standardization. I hardly think the Interstate Commerce Commission reports are a fair basis to be a determining factor in the establishment of a standard frequency. The Interstate Commerce Commission report includes all the transcontinental lines, and there is no doubt that those lines which have been unassailed yet by electricity could be electrified a great deal cheaper with low-frequency than with high-frequency apparatus, but I do not think that this fact should influence us. I think it is a misleading factor. We must not forget that the electrification of steam railways we are going to consider for the present are to be intimately connected with 25-cycle plants now in operation. It is possible that all of us may see a transcontinental road electrified, but I do not think that that ought to influence us in the determination of a standard frequency.

What " may be " should not decide this question but " what is." I think we should remember the fixed charges associated with 25-cycle plants that have not been taken into account in this report, and that the new frequency universally applied would make it necessary to re-equip all these plants operated upon what may now be termed a standard frequency; namely, 25 cycles.

I believe that for power transmission purposes we will all agree that 25 cycles has nearly occupied the position of a standard frequency. Now then, the fixed charges of the properties operated upon a 25-cycle frequency can later be taken care of by a properly provided depreciation figure or sinking-fund, and at the expiration of the depreciation periods we can avail ourselves of the greater data to decide which should be the standard frequency. The gradual interchange of the two frequencies can then be effected without hindrance to operation.

I have not time here to go into the details of this change, but I am sure all of us are agreed that this can be done. I am in favor of having more data and in letting the future consideration of the new data, in connection with the old, decide the proper standard frequency

O. S. Lyford Jr.: This paper is a prophecy. It is interesting to note that the fulfilment of the prophecy has already begun One of the oldest railroads in the country has proved itself the most progressive and has during this present week put into commercial service an electric traction system which embodies most of the features which the authors have assumed as probable characteristics of the standard of the future. Two other roads referred to in the paper have made a start in the direction proposed, but the Erie was the first to arrive. On January 22 the Erie Railroad ran its first electric train into Rochester.

The essential features of the Erie equipment are as follows:

Single-phase railway motors.

Multiple-unit control.

Pantagraph trolley.

Trolley wire supported with steel catenary construction at a height of 22 feet, except under bridges.

Trolley voltage. 11,000.

One sub-station feeding 34 miles of track.

Power received from a power station 90 miles away over a 60,000-volt transmission line.

The conditions are in many ways almost identical with the assumptions made by the authors.

I may say that the operation of the entire equipment was perfect and fully demonstrated the sufficiency and general practicability of the system. On the return trip the Vice-president's private car was hauled as a trailer, resulting in a total weight of train 22 per cent. heavier than that for which the motors were designed. This was on icy, slippery rails.

The impression given by the overhead catenary construction is that it is the adequate thing for heavy railroading. An

11,000-volt trolley wire so supported is a safe proposition. The 11,000-volt wires on the car are so short and so well guarded that they are not a source of increased danger, and all the other wires, housed in the usual way, and operated at only one-half the usual voltage, are unusually safe.

The system in this case is necessarily operated at 25 cycles, as the power comes from one of the Niagara Falls plants which are all built for 25 cycles. The advantage of the lower frequency is apparent, however, Trucks of unusual size are entirely filled with 100-h.p. motors. At 15 cycles, motors of 150 h.p. capacity could be used on the same trucks.

Referring to that part of the paper which relates to comparative costs of operation, more emphasis should be placed on the tabular matter and the deductions made therefrom. The one question is: can steam railroads be operated more economically by electricity? The three items which I presume will be most questioned are Items 12, " Repairs and Renewals of Locomotives;" Item 21, " Engine and Roundhouse Men;" and Item 22, " Fuel for Locomotives," or, in the case of the electric work, the cost of power delivered to the locomotive. I do not propose to discuss these different items in detail, but I would like to point out the fact that they might even be doubled, and still the electrical operation would not cost more than steam. Those of us who have had occasion to study different specific problems have found that the adoption of electric traction, particularly if a high-voltage trolley is used, will not mean an operating cost greater than the cost of steam, and in many cases the saving is considerable. In other words, specific cases which have been investigated, as well as this study of the problem as a whole, show that electric traction is commercially practicable for such lines as can provide for the initial investment. Furthermore, the advantages to be gained by electric traction, due to increased facility of operation and increased loads which can be carried, have not been capitalized in this paper.

The trunk lines of the country are confronted with the problem of more capacity, as has recently been strongly emphasized by Mr. J. J. Hill. There is no doubt but that more traffic can be handled with electric than with steam locomotives, and, at equal cost per locomotive-mile electric traction can be adopted to great advantage by the railroads of this country. On such an occasion as this we should place emphasis on this one important fact and not get into too much discussion of details.

C. L. de Muralt: Mr. Stillwell and Mr. Putnam have covered the questions of comparative energy consumption and comparative operating costs so ably and so fully that there is not much room left for discussion on these points. But on the subject of comparative speed and power characteristics of the various types of locomotives I believe I am in a position to add a few figures which may be of some interest to you. I have had occasion to make an investigation into the hauling capacities of certain locomotives when operating under heavy load conditions. The diagrams compiled during this investigation showed so strikingly the superiority of the electric locomotives over their steam competitors, and, incidentally, also the great superiority of the three-phase aternating-current locomotives over any other type of electric locomotive, that I thought it worth while to elaborate the results somewhat to present them for your consideration.

To make the comparison as broad as possible I have taken what I thought to be the most representative locomotives of their respective classes: the latest direct-current locomotives of the New York Central and Hudson River Railroad, the single-phase alternating-current locomotive of the New York, New Haven and Hartford Railroad, and a European three-phase alternating-current locomotive of the type used by the Italian State Railways. And with these I have compared a Pacific, an Atlantic, and a Consolidation type steam locomotive of recent American Locomotive Company's design—all the steam locomotives being chosen with reference to possessing the greatest possible power; that is, the greatest feasible heating surface, consistent with their weight on drivers.

Detailed descriptions of the mechanical and electrical features of the New York Central direct-current locomotive have appeared in the technical press[1]. So I will simply repeat here some characteristic figures required for the comparison:

Total weight, 95 tons.
Weight on drivers, 68 tons.
Nominal rated horse power, 2200.
Maximum horse power, 3000.
Maximum tractive effort at starting, 34,000 lb.
Three main running speeds:
  a. Four motors in series.
  b. Two groups in parallel, each of two motors in series.
  c. Four motors in parallel.
Normal operating pressure of motors, 600 volts.

On the New York, New Haven and Hartford single-phase alternating-current locomotive, complete data were published last year[2], and I merely extract the following figures:

Total weight, 85 tons.
Weight on drivers, 85 tons.
Nominal rated horse power, 1000.
Horse power in continuous running, 800.
Maximum tractive effort at starting, 42,500 lb.
Speed controlled by voltage variation, motors permanently connected two in series, two in parallel, numerous speed steps.
Normal operating pressure of motors, 235 volts.

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[1] *Street Railway Journal*, November 19, 1904.
[2] *Street Railway Journal*, April 14, 1906.

The three-phase alternating-current locomotive has four driving axles and three motors suspended between them, and the locomotive possesses the following characteristics:

Total weight, 95 tons.
Weight on drivers, 95 tons.
Nominal rated horse power, 2250.
Maximum horse power, about six times nominal full load rating.
Maximum tractive effort at starting, 47,500 lb.
Three main running speeds:
  a. Three motors in cascade connection.
  b. Two motors in cascade connection.
  c. Two motors in parallel.
Normal operating pressure of motors, 3000 volts.

A locomotive of exactly the same type, but slightly lighter, has the following typical dimensions:

Total weight 85 tons.
Weight on drivers, 85 tons.
Nominal rated horse power, 2000.

I refer to the heavier locomotive as type A, and the lighter one as type B.

Descriptions of the three steam locomotives will be found in the American Locomotive Company's publication. The principal features of the Pacific type locomotive (No. 1212, of the Southern Railway) are as follows:

Total weight including tender,	175	tons.
Total weight of engine alone,	109	"
Weight on drivers,	67	"
Cylinder diameter,	22	inches.
Stroke of piston,	28	"
Diameter of drivers,	72.5	"
Total heating surface,	3895	sq. ft.
Maximum sustained horse power,	1640	
Maximum tractive effort at starting,	33,500	lb.

The Atlantic type of locomotive (No. 3000, of the New York Central and Hudson River Railroad) has the following characteristics:

Total weight including tender,	161	tons.
Total weight engine alone,	100	"
Weight on drivers,	55	"
Cylinder diameters,	15½ and 25	in.
Stroke of piston,	26	"
Diameter of drivers,	79	"
Total heating surface,	3445	sq. ft.
Maximum sustained horse power,	1360	
Maximum tractive effort at starting,	27,500	lb.

And, the Consolidation type locomotive (No. 221, of the Delaware and Hudson Railway) may be briefly described as follows:

Total weight including tender,	164	tons.
Total weight engine alone,	96.5	"
Weight on drivers,	85	"
Cylinder diameter,	21	in.
Stroke of piston,	30	"
Diameter of drivers,	57	"
Total heating surface,	3408	sq. ft.
Maximum sustained horse power,	1020	
Maximum tractive effort at starting,	42 500	lb.

All of these locomotives have a maximum speed of about 70 miles per hour except the Consolidation, the maximum speed of which is about 40 to 45 miles per hour.

The running characteristics, expressed in the shape of tractive effort, speed curves, of all of these locomotives are indicated in Fig. 1.

All of these curves start at a point corresponding to the maximum tractive effort which is obtainable by the full use of the adhesive weight of the locomotive, just below the point where the wheels begin to slip. This maximum tractive effort, dependent only on the adhesive weight, can for each locomotive be counted upon up to a certain well determined speed. Beyond that point, clearly shown in the curves, the maximum tractive effort is independent of the adhesive weight and dependent on the maximum power which the locomotive can develop. And it is from this point that the various locomotives show marked differences in behavior.

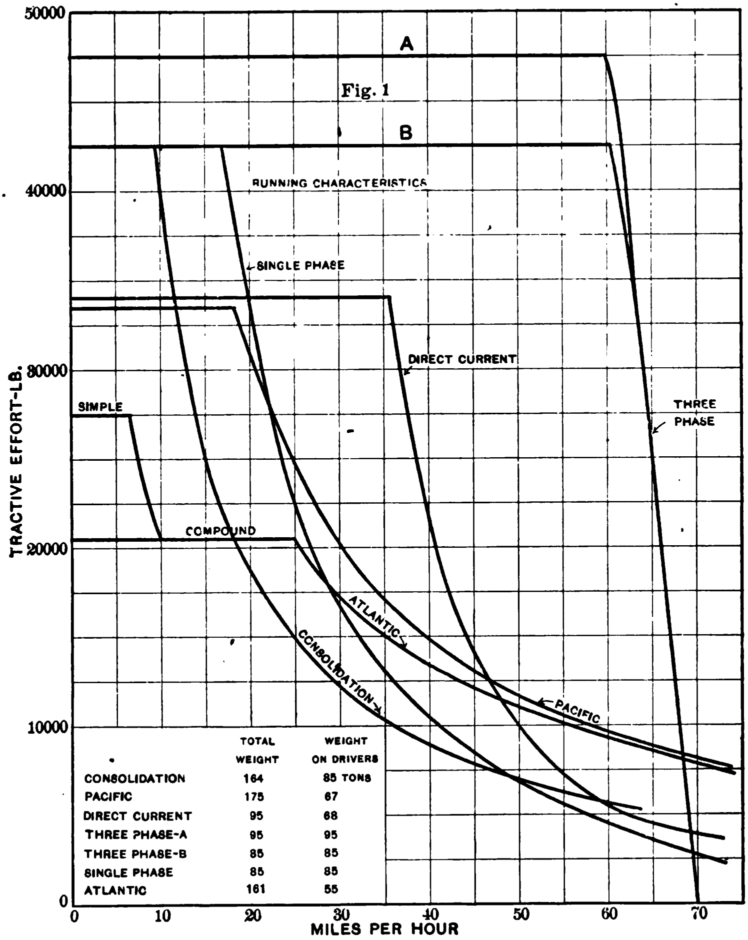
The horse power which a steam locomotive can develop is determined by the amount of water which the boiler can evaporate and the economy of the cylinders. If W represents the pounds of water evaporated into steam per hour at the given pressure, and N the water rate of the cylinders in pounds of steam per indicated horse power hour, then the maximum indicated or cylinder horse power in this part of the curve is $\frac{W}{N}$. Tests conducted under the auspices of the Pennsylvania Railroad at the Louisiana Purchase Exposition in 1904, showed that the evaporation per square foot of heating surface per hour for different types of locomotives varied between 8 and 16 pounds, also that the steam consumption of the cylinders averages 23.7 to 29 pounds per indicated horse power-hour. The largest Consolidation locomotive built, with 100 tons on drivers, has about 4000 square feet of heating surface; the largest Pacific locomotive, with 67 tons on drivers, about 3900 square feet; and the largest Atlantic, with 57.5 tons on drivers, about 3600 square feet. The average evaporation and the average economy under service, not test, conditions, is approximately 12 pounds per square foot of heating surface per hour, and 27 pounds per indicated horse power-hour, respectively. For one horse power developed in the cylinders there must thus be 2.25 square feet of heating surface in the boiler, or:

Cylinder horse power = 0.43 × heating surface in square feet and:

$$\text{Tractive effort} = \frac{375 \times \text{cylinder horse power}}{\text{speed in miles per hour}}, \text{—frictional}$$

tractive effort =

$$\frac{161 \times \text{heating surface in square feet}}{\text{speed in miles per hour}} \text{—frictional tractive effort.}$$



	TOTAL WEIGHT	WEIGHT ON DRIVERS
CONSOLIDATION	164	85 TONS
PACIFIC	175	67
DIRECT CURRENT	95	68
THREE PHASE-A	95	95
THREE PHASE-B	85	85
SINGLE PHASE	85	85
ATLANTIC	161	55

FIG. 1.

The machine efficiency varies in different types, over the range of speeds, from about 74% to 93%. The mean effective pressure corresponding to frictional loss is very nearly constant for all speeds and cut-offs, and averages 3.8 pounds per square inch. The maximum tractive effort, therefore, is given by the relation:

$$\text{Tractive effort} = \frac{161 \times \text{heating surface in sq. ft.}}{\text{speed in miles per hour,}} - \frac{3.8\, d^2 \cdot L}{D}$$

where d is diameter of cylinder in inches, L the length of stroke in feet, and D the diameter of driver in feet. This formula, developed by Professor Goss,[1] for simple engines, has been found to corroborate actual tests with exceedingly good accuracy. The majority of the curve sheets in the Pennsylvania tests referred to, show the calculated and test curves in practical coincidence. The curve of the Atlantic type, four-cylinder balanced compound locomotives, No. 3000 of the New York Central and Hudson River Railroad, was plotted from an actual test made at St. Louis.

The curve obtained from the above equation represents the normal continuous output of the steam locomotive. This continuous output is practically the maximum output, since the overload capacity of the steam locomotive is limited to perhaps 25% for periods not exceeding 5 minutes, on account of the impossibility of forcing the boiler above its normal capacity for extended periods.

Electric locomotives, on the contrary, can sustain overloads of considerably greater magnitude for much longer periods of time, without any difficulty.

The curves of the direct-current and the single-phase alternating-current locomotives are very similar in character to the curves of the steam locomotives. These electric locomotives have motors, with so-called series characteristics, that slow down in speed with any increase in load. The direct-current and the single-phase electric locomotives, in common with the steam locomotive, will therefore reduce their speed when they are called upon to haul an increase in load, either in the shape of a heavier train or when running up-grade.

This feature is clearly shown by the curves in Fig. 1, and it is quite interesting to note that the curves of the steam and electric locomotives cross each other. In other words, the tractive effort of the direct-current and single-phase alternating current locomotives, which is better than that of the steam locomotive at low speeds, actually drops off considerably faster with increasing speed, until it is much worse than that of the steam locomotive at high speeds. In fact, if we consider carefully, the curve of the steam locomotive is the result of practically constant power output, while with the direct-current and single-phase alternating-current locomotive the power output as such diminishes together with the tractive effort.

But the greater advantage of the electric locomotive lies in the fact that it can utilize its weight very much better than can the steam locomotive; and if the actual values of tractive effort taken from the curves are compared with the weights of the

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[1] New England Railroad Club, December, 1901.

corresponding locomotives it will be found that the direct-current and the single-phase alternating-current locomotives are capable at low speeds of exerting a very much greater tractive effort proportional to their weight than can the steam locomotives, and even at high speeds their proportional performance is better than that of the steam locomotive.

An additional, and perhaps even more important advantage of these electric locomotives over their steam competitors, lies in the fact that the electric locomotive can readily respond to almost any kind of overload demand. As a matter of fact, a prolonged grade for instance, may seriously decrease the usefulness of a given steam locomotive, due to the impossibility of forcing the latter's boiler for any considerable length of time above rated capacity ,while the electric locomotive will slow down, of course, but will, with the assistance of the power house, carry great overloads for any reasonable length of time.

The three-phase alternating-current locomotive not only accomodates itself to such increased demands on its hauling power, but it does so without any great drop in speed, and automatically adjusts its power to the demand. If at 1500 horse power normal output the motors of a given three-phase locomotive have a 2% slip, then at five times the normal tractive effort the slip will be approximately 10%, and the speed will drop from 68.5 to 63.0 miles per hour. Three-phase induction motors of this size (750 horse power) can be built with a maximum torque of 6 to 7 times full load-torque with very good electric qualities. And, notwithstanding the objection sometimes urged that the design must be very liberal for such service, it remains a fact that the three-phase motor can do what the others cannot do, and its intrinsic lighter weight per horse power, its higher efficiency, its more economical distributed winding, and the absence of the commutator, keep down the cost of the three-phase locomotive within the limits governed by competition.

It goes without saying that this constant-speed variable-power characteristic of the three-phase locomotive need not necessarily be made use of in cases where a decrease in speed is no serious objection, while it may perhaps be desired to keep the power within limits. In such cases the three-phase locomotive can just as well be run at lower speeds for the heavier draw-bar pulls. But it may be well to point out here that the power required; for instance, for a 300-ton train running at about 70 miles per hour on a grade of 0.335%, is the same as that required to accelerate the same train on the level with an initial acceleration of 0.56 miles per hour per second. Inasmuch as the system will be designed for the maximum power demands caused by the heaviest trains accelerating, no additional investment in copper or machinery will be required by this constant-speed, variable-power characteristic of the three-phase locomotive.

Instead of saying that the three-phase locomotive is capable of maintaining practically constant speed under any load, while direct-current and single-phase locomotives will drop in speed with increasing load, the thesis may be reversed and the equally true statement be made that the three-phase locomotive is able to develop a certain given tractive effort from zero clear up to practically maximum speed, while the tractive effort of the direct-current and the single-phase locomotives will fall off seriously with increasing speeds, and at maximum speed is only a fraction of what it was at low speed. The curve of the direct-current locomotive shows, for instance, a drop from more than 3000 horse power at 36 miles per hour to only 960 horse power at 60 miles per hour, and the curve of the single-phase locomotive a drop from about 1540 horse power at 23 miles per hour to only 670 horse power at 60 miles per hour. And this is not a question of liberal design, but an inherent unalterable characteristic of all locomotives using series motors.

These features are brought out very clearly by the curves of Fig. 1, but a few hypothetical examples may go to show just exactly how these characteristics affect the actual hauling of trains.

Let us take a locomotive capable of hauling a 150-ton train, and run it over a given stretch in, say 16 minutes, by the use of a maximum running speed of about 65 miles per hour. Now increase the train-weight to 300 tons. The three-phase locomotive will haul the heavier train over the given stretch as before, in 16 minutes, but the direct-current locomotive or the single-phase alternating-current locomotive will have to drop in speed, and will now take 18 minutes to cover the same distance. A loss of over 10% in time, which loss increases with increasing load.

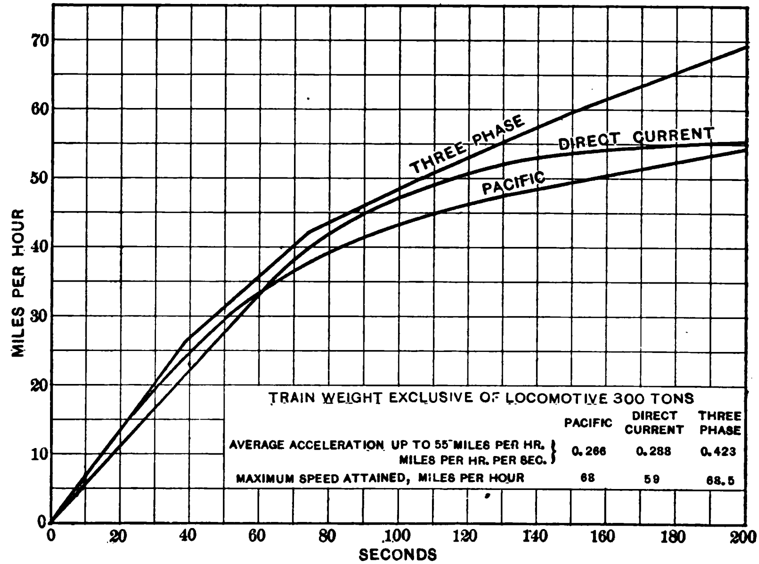
Or take a line of track with one or more grades. Hauling trains of the same weight, the direct-current locomotive and the single-phase locomotive will, compared with the three-phase locomotive, lose a certain amount of time at each grade, and their total running time will, with the same maximum speed, be necessarily considerably poorer than that of the three-phase locomotive.

Or, take the actual curves of Fig. 1 and send the locomotives over a level line at an average running speed of 60 miles per hour, which corresponds to a schedule speed of about 50 miles per hour with stops about 15 miles apart. We then find the maximum tractive effort for each locomotive, and the maximum trailing load which each can haul (assuming a train resistance of 17 pounds per ton) to be as follows:

	Maximum tractive effort	Weight of locomotive and tender	Trailing train weight
Single phase .	4250 pounds	85 tons	165 tons
Direct current	6000 "	95 "	258 "
Atlantic......	9250 "	161 "	382 "
Pacific.......	9750 "	175 "	398 "
Three-phase	9375 "	95 "	457 "

If we investigate the maximum grade which each locomotive can take with a given train at a given speed we shall find the same order of things. It seems, therefore, entirely fair to draw the broad conclusion that for its weight the three-phase locomotive is by far the most powerful hauling engine extant.

To complete the comparison I have plotted a few curves Figs. 2, 3, and 4) showing the relative accelerations which can be obtained from the various locomotives above referred to, and I have endeavored to bring together for this purpose locomotives directly comparable, as much as possible, with reference to their weight characteristics. In Fig. 2, I compare the Pacific type steam locomotive (109 tons, 67 tons on drivers) with the direct-current locomotive (95 tons, 68 tons on drivers) and the heavier of the two three-phase locomotives (95 tons, all on drivers). On Fig. 3 the Atlantic type (100 tons, 55 tons on drivers), a most powerful engine for its weight, is compared with the single-phase locomotive (85 tons, all on drivers) and the lighter three-phase locomotive (85 tons, all on drivers). And on Fig. 4 the Consolidation (96.5 tons, 85 tons on drivers) is compared with the lighter three-phase locomotive (85 tons, all on drivers). These weights are sufficiently close together to permit a fair comparison, but I may point out that to eliminate even these small differences in weight, I have assumed that the electric locomotives would use only such portion of their adhesive weight as corresponds to the adhesive weight of the steam locomotive compared with it.



TRAIN WEIGHT EXCLUSIVE OF LOCOMOTIVE 300 TONS

	PACIFIC	DIRECT CURRENT	THREE PHASE
AVERAGE ACCELERATION UP TO 55 MILES PER HR. MILES PER HR. PER SEC.	0.266	0.288	0.423
MAXIMUM SPEED ATTAINED, MILES PER HOUR	68	59	68.5

FIG. 2.

This being strictly a comparison of acceleration characteristics, the period of acceleration was assumed to extend to a speed of 55 miles per hour only, so as not to be unfair to those locomotives having a very low rate of acceleration at high speeds.

In Fig. 2 a six-car train, weighing 300 tons exclusive of locomotive, was assumed. The steam locomotive uses its full adhesive weight up to 18.4 miles per hour, accelerating at 0.653 miles per hour per second. From then on the tractive effort drops according to the curve in Fig. 1, and the rate of acceleration correspondingly. A speed of 55 miles per hour is reached after about 200 seconds. The direct-current locomotive accelerates with 875 amperes per motor constant input, 2100 kilowatts maximum, up to 38 miles per hour, from which point on it accelerates on the motor curve at a constantly decreasing rate, until 55 miles per hour is reached, after about 180 seconds. The three-phase locomotive accelerates with a constant input of 2450 kilovolt-amperes, 2200 kilowatts maximum, with three different rates of acceleration corresponding to the three motor connections, reaching 55 miles per hour after about 130 seconds. The energy consumption for the direct-current locomotive and the three-phase locomotive is the same and equal to about 300,000 kilowatt-seconds.

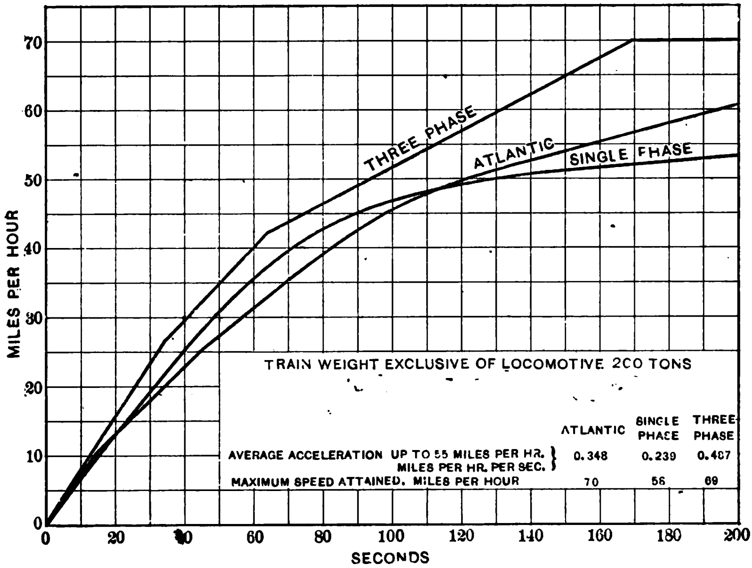


FIG. 3.

In Fig. 3 where the train-weight is assumed to be 200 tons exclusive of locomotive, the steam locomotive again starts with the use of full adhesive weight, and although having at first a low rate of acceleration, it uses its great capacity at higher speeds to full advantage, and reaches 55 miles per hour after about 160 seconds. The single-phase locomotive and the three-phase locomotive start with the same initial input of 2,000 kilovolt-amperes, which, however, gives the three-phase locomotive a better initial tractive effort on account of its better power-factor and efficiency. After 33 miles per hour, the single-phase locomotive accelerates on the motor curve at a constantly diminishing rate of acceleration while the three-phase locomotive utilizes the same initial input up to full speed. A speed of 55 miles per hour is reached by the single-phase locomotive after about 220 seconds, and by the three-phase locomotive after about 115 seconds.

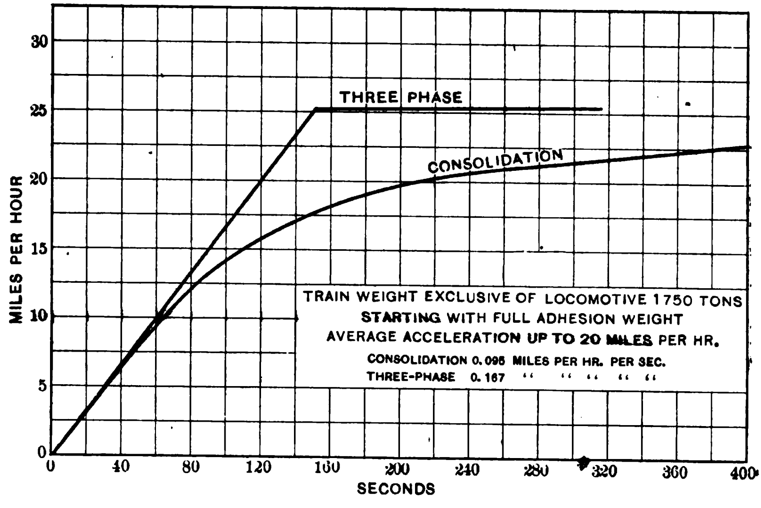


FIG. 4.

In Fig. 4 both the steam locomotive and the three-phase locomotive start with full adhesive weight and accelerate a 1750-ton freight train up to 20 miles per hour at the rate of 0.095 and 0.167 miles per hour per second, respectively, reaching 20 miles per hour after about 200 seconds and about 120 seconds, respectively. By reducing the input for the electric locomotive the acceleration period would be lengthened, but the performance would still excel that of the steam locomotive.

The three-phase locomotive seems, therefore, to be ahead of its competitors also in accelerating qualities, which is quite natural because it is the only one which can utilize a constant input up to full running speed. The three-phase locomotive is mathematically sure of reaching full speed after a certain predetermined time. Locomotives with series characteristics will approach full speed so slowly, that they very frequently do not reach it at all unless the distance between stops is very great.

CONCLUSION

The constantly increasing business on trunk and suburban lines will have as an inevitable result—track congestion. On certain railroads trains are now so heavy, and run at such high speeds, as to tax the capacity of the most powerful steam locomotives to the limit, and the headway between trains is as small as permissible. Here, then, electrification becomes an absolute necessity if the traffic capacity of the lines is to be increased without the tremendous expense of adding new tracks. We have seen that electric locomotives are in themselves more powerful than steam locomotives of even weight; but it is furthermore possible to couple two or more electric locomotives together by multiple-control connections, and to operate them for all practical purposes as one locomotive by one man. Thus an unlimited amount of power can be concentrated in one unit and traffic can be handled both in increased train weights, not limited by considerations of gradients, and also at higher speeds than are at present employed. That the three-phase alternating-current locomotive is by far the most suitable engine for this purpose I believe to have demonstrated above.

A. H. Armstrong: We have listened to the advocates of the 600-volt and the 1200-volt direct-current systems and the various alternating-current motor systems, and have learned that each of these types of motors possesses qualifications that permit the construction of an electric locomotive much superior to the present steam locomotive. It strikes me that each speaker uses his own individual method of saying the same thing—that we have in the electric locomotive a piece of apparatus which can accomplish results not possible with the present steam locomotive. We have outgrown the days of a machine having an indicated output under 2,000 horse power, a maintenance charge of eight to ten cents per locomotive-mile under the best conditions of level-track operation, and double this amount when the conditions are adverse; and we have at our disposal a locomotive that gave a maintenance charge of less than one and one-half cents per locomotive-mile during an endurance test of 50,000 miles, a concentrated output of 2200 horse power nominal, and fifty per cent. increase for unlimited periods by using forced ventilation. I believe that with the assets we have in the electric locomotive, the day has come when we can approach large railroad problems with supreme confidence of winning out over steam competition. It is not a case of the type of apparatus to be used, nor is it a question of frequency, as each case must be considered by itself in order to make the best individual showing for the local conditions involved. Ten years from now we will still be disputing over the question of frequency, alternating-current or direct-current operation, types of motors, and control to be used, etc. Looking back on the history of the steam locomotive, the same lack of agreement is apparent, and even to-day there is no standard type of steam locomotive receiving the universal approval of engineers and operators.

It is not necessary at the present time to standardize electric locomotives or systems of electrical distribution, as we have not yet demonstrated the best type of motor and the apparatus best suited to take care of the needs of both heavy and light electric railroading. No standardizing can be attempted without full experimental and operating data, showing without question that a particular type of apparatus is the survival of the fittest. I regret that no such full operating data are in existence to-day; in fact, no locomotive of the single-phase alternating-current or 1200 volts direct-current type is yet operating in commercial service.

The electric motor provides opportunity for doing something that cannot be accomplished by steam, and this is the reason why it has superseded steam power in the past and will continue to replace the steam locomotive in the future. It is not a question of petty economies effected; it is the broader question of increased facilities, increased gross receipts, and increased opportunities for earning money by means of the electric motor that makes it a successful revival of the steam locomotive. This point has been illustrated in the past by the entire elimination of the steam locomotive in urban and short-haul suburban work. It is being demonstrated in the big terminal electrifications now going on in and around New York. The managers of our large western roads are seriously considering the substitution of electricity for steam, based solely upon the fact that their roads are in need of a type of locomotive which can surpass the best performance of the steam locomotive as constructed to-day, or as foreseen in the future. A steam locomotive having a capacity of 500 tons trailing on a two per cent. grade is going to be a thing of the past as soon as full appreciation is paid to the fact that it can be replaced by an electric locomotive capable of hauling increased tonnage at double the speed. In face of such facts it is a matter of detail consideration to discuss the question of frequency and types of motive power when there are not sufficient operating data and experience at our disposal to enable one type of motor and one system of distribution to stand above all others as possessing qualifications demanding its universal adoption, and, hence, its standardization.

N. W. Storer: It seems to me that the whole question of the electrification of steam railroads comes down to one of dollars and cents, and the system that can be operated and installed for the least money will be the one to be adopted. As may be seen, there are many different ideas on the same question. Many engineers are working on designs of electric locomotives to meet the many requirements which are constantly being requested of manufacturing companies. I have worked over them for some time past, and every time a new proposition comes in, the matter of frequency, or alternating-current or direct-current operation must be decided. It is a question whether the problem can be solved by the simple direct-current system, which our friend, the father of electricity, loves so well, or whether we must go to something higher and nobler up with our voltage and up in the air with our trolley. Our experience is that the decision is generally in favor of locomotive of the single-phase type. I have considered the direct-current locomotive, and the three-phase locomotive, prayerfully and carefully but, it does not seem to me that either one of these is the type of locomotive which will meet the requirements of the railways of this country. The direct-current locomotive as it has been designed certainly will not do it. In speed characteristics, the single-phase locomotive pleases me much better than the three-phase.

The single-phase locomotive seems to offer the greatest possibilities. With it, we can not only operate up to what might be called the normal speed of a locomotive, but far beyond that. High speeds become simply a question of applying higher voltages from the transformer to the terminals of the motor. The same locomotive can be operated just as well at 10, 15, 20, or 25 per cent. above what might be called its normal voltage as the direct-current locomotive can be operated at it normal voltage. The question of commutation in the single-phase motor is not so much one of voltage as one of induction in the field, one of current which the motor is carrying or, in other words, of the tractive effort which it is exerting.

Every time a single-phase motor is designed for heavy work, the question of frequency arises, and it always works out much better for 15 cycles, for this reason: at least 30 per cent. greater output can be got from motors at 15 cycles than from motors of the same size operated at 25 cycles. That means that at the limit there must be 30 per cent. more motors if the motor is to operate on 25 cycles than would be needed on 15 cycles. That not only increases the cost of motors very much, but increases the cost of all mechanical parts, the motor-trucks must be heavier than trail-trucks—the entire equipment must necessarily be heavier.

The question of efficiency alone is bound to influence the matter very largely. The 15-cycle motor approaches closely the efficiency reached by the direct-current motor, and there is so little difference that it can hardly be detected. In power-factor it comes very close to the direct-current motor. It is above 90 per cent. throughout the entire range of loads in most sizes—it is practically unity.

The saving in cost of locomotives which might be effected by using 15 cycles instead of 25 cycles is mentioned in the paper, and I am bound to say that the difference which is shown is entirely inadequate to cover what in our opinion it would be. I should say that the difference would be at least $5,000, rather than $1,000. That makes a difference which seems to me to be overwhelmingly in favor of the 15 cycles; it is due largely to the number of motors.

In regard to the lighting of the cars, I believe that satisfactory lighting can be obtained with 15 cycles, by using a low-voltage lamp having a heavy filament. A lamp designed 15 volts, to operate on a 15-cycle circuit, will give just as good light and as perfect illumination as the ordinary incandescent lamp on a 25-cyle circuit. It will be entirely satisfactory for the lighting of cars. The many other questions which come up in connection with railway installations will of course influence the choice of frequency very largely, but as I said in the beginning, it is simply a matter of dollars and cents that will determine whether 15 cycles or 25 cycles is going to be adopted for railway work.

William McClellan: Having passed through the experience of equipping some cars with single-phase motors and proper multiple-unit control for 11,000 volts, I believe firmly that the solution of the railroad problem is going to be by means of the 11,000-volt system. Perhaps not exactly 11,000 volts, but a high-voltage overhead trolley with a single-phase motor. In spite of the fact that a heavier motor is needed for the power developed; in spite of the fact that the sub-station is separated into pieces carried on the motor-cars making a large amount of ton-miles in the course of a year—as a whole the system provides a better solution for trunk-line electrification than any other in sight at the present time. This is particularly true if engineers can be brought to think that 15 cycles is better than 25. I, for one, after a very careful examination of every argument, feel sure that nothing stands in the way of the standardizing of this frequency.

Although the steam railroads have not standardized as to details, they have standardized so that they can make necessary interchange of equipment. Electrical engineers must do such necessary standardizing at once. Unless this standardizing is done at once there might result one kind of trolley on this road running locomotives of one type, and another type on that road; this condition might not prove serious with electric locomotives, but if cars cannot be exchanged freely it will be impossible to electrify the railroads of the country, particularly on the grand scale suggested in this paper. So, therefore, I certainly agree that it would be advisable and possible to standardize immediately certain features of railroad practice, the height of trolley, the location of the third-rail, and the voltage and frequency at the trolley and third-rail.

In spite of the fact that the two great manufacturing companies in this country have different systems of control, I see no reason why the train-line jumper should not be standardized as to position and number of wires. That would solve a great many problems in itself, particularly if the jumper could also connect a heating and lighting bus-bar at a standard voltage, making thereby one jumper between the cars to be handled in addition to the air-brake connections. The largest jumper I know of has twelve conductors for the train line, and it is probable that this number is a maximum. Any particular system could use as many of these conductors as desirable. Such an arrangement would permit easy interchange of Pullmans, express cars, mail cars, fast-freight cars, etc., which might have to be used as trailers in multiple-unit trains of different systems.

The above features include all necessary standardization. This, I believe, is the only standardization that is possible or ought to be allowed at present, because anything else would stifle proper advance in the art.

The firm with which I am associated has always found it difficult to derive useful data from published information on costs of locomotive operation. Therefore, another scheme was adopted. It was to take several railroad divisions having different kinds of traffic, a division with large passenger traffic, another having large freight traffic, and another having a good mixed traffic, and if possible get costs on these. In this way we hoped to arrive at some general figures which could be relied upon. I am free to say that while we did have some success and did arrive at some results, on the whole they were unsatisfactory. It was difficult to obtain any reliable costs for coal, wood, and water stations; but the results given in the paper for maintenance of way and structures are as nearly correct as can be stated.

When we came to Item 12, all figures were very unreliable. I believe the only useful method is the one Mr. Murray has adopted of watching very carefully certain locomotives in service. One scheme we tried was to assume that we could substract the cost of boiler repairs and leave only engine repairs, and by some process of assumption get a comparison between costs of electric locomotives and steam locomotives. We found a pretty good agreement that boiler repairs were one-sixth of the total repairs of the engine, but we could find no railroad people who would agree in the assumption that an electric locomotive would cost anything less for maintenance than the machine part of a steam locomotive. Assuming the figures are the same, the maintenance on the electric locomotive might then be considered five-sixths of the present cost of the steam locomotive.

I ask you to beware of any figures given on maintenance by European railways, for the reason that labor is cheap in Europe; and secondly, a great deal of care is given to operation, and costs are likely to be very low. Neither can the cost of running a locomotive 50,000 miles, where it has been in the hands of trained electrical engineers, be taken as a comparative figure for a locomotive running day in and day out, put in the roundhouse at intervals, given more or less attention, but most of the time in the hands of a road engineer who may or may not be able to take care of it.

Some very interesting results were obtained in connection with Item 21. In the first place, I am confident that a "deadman controller" is as reliable as a second engineman, and makes his presence wholly unnecessary. In the second place, a very complete study by a prominent steam railroad man at several different roundhouses at which forty to sixty locomotives were handled per day showed a total cost per engine handled of $1.18. This included all operations from the time the engineman dropped his engine until he took it again. It was found that 54 per cent. of this was peculiar to steam, and could be omitted with electric locomotives. How much, however, would have to be added as peculiar to electric locomotives could not be satisfactorily estimated.

Forsaking figures, there are broad lines on which we may approach any railroad electrification problem and hope to solve it. These are:

1. The flexibility of motor equipment permitting multiple-unit operation for passenger and freight service in a variety of ways.
2. The possible increase in road-miles per locomotive on account of decreased time in roundhouse, etc. An average steam locomotive, making perhaps 3,000 miles per month in freight service, is about 45% of its time on the road, 30% in the roundhouse, and 25% in the yard awaiting orders, etc.
3. The possibility of generating power cheaply by locating the power plants close to coal mines, which will avoid hauling of the coal, and also by making use of large number of small water powers which, if properly developed, amount to a great asset for the railroad; water powers which would be of little use to an individual, but might be of great use to the railroad because its load is distributed over a large territory.

W. I. Slichter: I have been particularly interested in that part of the paper relating to the choice of frequency for single-phase railway work. I have studied the subject for some time and believe there is no question but that a lower frequency is very desirable for the single-phase motor.

There seems to be a unanimous opinion that the output of the motor may be increased some 30 or 35 per cent. by a decrease in frequency from 25 to 15 cycles. In many cases this will make it possible to build in the limited space available on the trucks of a car, a motor of sufficient power to perform the service required. whereas at 25 cycles it would be impossible to obtain sufficient power. But as Mr. Stillwell has pointed out, we must consider how much this change will cost. The other parts of the system, except the transmission line, are more expensive at the lower frequency.

The generator itself may be increased in cost anywhere from 15 to 50%, depending on the size and design. This is due to the fact that a speed corresponding to 15 cycles will be difficult to obtain in turbines, while for slow-speed engine-driven units there will be no great difficulties.

Transformers are increased in cost about 20% by the change, while the distributing system will be decreased about 10% in cost.

Considering, first, an interurban road in which the amount of motive power is small compared with that considered for a large steam road as discussed by Messrs. Stillwell and Putnam, the relative costs of the various parts of an installation are fairly represented as follows:

	25 cycles	15 cycles
Generating station........	34.4%	38 %
Sub-stations...............	1.8%	2.1%
Low-tension construction..	14.8%	14.8%
Low-tension copper........	12. %	11. %
High-tension line..........	5.4%	5.4%
Bonding...................	7. %	7. %
Equipments and cars......	24.6%	23. %
	100 %	101.3%

For this interurban road then a 15-cycle installation would be more expensive.

But turning to a road which approximates steam railroad conditions, the cost of the equipment forms a much larger proportion of the total cost, while the increase in the cost of the power station is not so great on account of the larger size of the units. This transfers the balance to the other side and the figures are similar to those given in the paper. This shows that as we approach heavy railroad work the greater will be the need for the lower frequency.

It has not been pointed out, however, that although the rated (one hour) output of the motor is increased some 35 per cent. by the change in frequency, this is only the output during acceleration, whereas the continuous output rating of the motor is not changed accordingly. For passenger service with long runs and a small percentage of acceleration, not as much is to be gained by the use of the lower frequency.

J. B. Whitehead: As I have listened to the discussion, a certain aspect of the question has suggested itself, and I venture to bring it forward. In considering an electrically propelled vehicle, I take it we may consider that vehicle best which possesses two characteristics to the greatest degree, other things being equal; and these characteristics are the degree to which the vehicle is self-contained and the greatest power that can be got into the space given to the motors. In speaking of the degree to which an electrically propelled vehicle is self-contained, I wish to draw attention to the fact that we may consider an electric locomotive or car more self-contained so far as it requires less attention from the outside. That is to say, the greater the distance between sub-stations and the less complicated the apparatus at the sub-stations, the better. In these respects the alternating-current has the advantages of the direct-current. If the advocates of the direct-current system, could bring forward apparatus that would operate and transmit at the same voltages that the alternating-current system does, a great deal of this discussion would not have taken place. From the standpoint of self-containment, I think that we must look for something from the direct-current side before we yield the position taken by the advocates of the alternating-current system.

It has been very interesting to hear the comments on the other aspect, the greater power which can be got into the space available for motors by reducing the frequency. If 15 cycles is the point at which the advantage of an increase of power within this space stops, being offset by the greater weight and greater cost of transformers, and the difficulties in the generating apparatus, then that is the frequency that will finally be adopted.

The problem is to do the right thing in the right way; and if we can stretch out more and more the distances between the points where the motor needs help from outside by using the alternating-current system, then the alternating-current system will prevail. The footnote suggests a danger from the rising potential of a broken bond, in the case of high-potential operation. I ask if there is any instance on record where there have been unpleasant results attendant upon a broken bond?

L. B. Stillwell: First, I shall reply to Mr. Whitehead's question. We have assumed in our estimate a No. 4/0 conductor in the track circuit in order to aviod the possibility of a dangerous potential on the track in case of broken bonds. My attention has never been called to any case in which danger has occurred from this cause, but it appears to me a theoretical possibility and we desire to make our estimates eminently fair to the steam side of this proposition.

I have been greatly gratified by the discussion on this paper, and I hope that members of the Institute who have additional concrete facts bearing upon the important question of frequency will contribute these facts by letter.

It is evident that the great majority of engineers present would admit that the question of frequency is settled decisively by the testimony we have had in favor of 15 cycles. The testimony of Mr. Lamme, the inventor of the single-phase motor; of Mr. Storer; of Mr. Slichter, and other men who have been active in their development and practical application, to my mind is conclusive as regards the performance of the motor, and they have testified that the difference in favor of 15 cycles, as measured at the draw-bar, is approximately one-third. When this fact is taken into consideration, in view of the general perspective of the problem, which we have endeavored to establish by considering the electrification of our railroads as a whole, it seems to me there is only one conclusion to draw.

In our estimates we calculated that the expenditure for electrical equipment of rolling stock, if the 25-cycle system were used, would approximate $450,000,000. Mr. Storer has stated that the difference in favor of 15 cycles would be at least $5,000 per locomotive, but his figure for the entire locomotive is considerably higher than that which we have assumed in our estimates, and therefore we may scale this $5,000 down to about $4,000. Applying this to 24,000 locomotives, the difference in favor of 15 cycles is $96,000,000, which is ten times the difference in cost of the power-house equipment which is adversely affected by a reduction of frequency.

I believe that to-day we are able wisely to standardize frequency as well as the position of the overload trolley. These things certainly should be agreed upon. The steam roads have standardized everything essential to the interchange of their rolling stock. We must follow that precedent or we shall get involved in all sorts of trouble.

Mr. Sprague is in favor of the direct-current system. He has done so much in the development and application of electric apparatus for traction purposes, first by the direct-current motor and more recently by the multiple-unit system of control, that I should be very sorry to see him make a serious mistake, and I hope that before he nails his flag to the 1500-volt direct-current masthead he will take into account all the evidence presented to-night.

Frank J. Sprague (by letter): Commenting briefly on some statements made by various speakers, which in one breath describe the perfection of results attained by 25-cycle motors and yet complain of their lack of capacity, I am reminded of a sign which I often see in the Subway cars: "We could not improve the powder, so we improved the box."

My criticism of the 25-cycle motor, which has been so well exploited, has not been because of the potential at which a trolley line must be operated. The relations of potential to size of conductor are really of such common knowledge in the primer classes of electrical engineering that it is hardly worth while to discuss that particular feature. Obviously, if alternating currents are to be used then just as high potentials as the physical facts will permit should be adopted, and there is nothing revolutionary in the use of 11,000 instead of 3,000 volts.

Capacity is the keynote of an equipment, and capacity is not measured alone by that of conductors, but ultimately also by motor equipments; and the entire testimony of this evening bears out my criticism, that the 25-cycle motor as constructed to-day does not under like conditions approach the capacity of the direct-current motor. It is proposed to increase this capacity of lowering the frequency. This, also, in itself is not a novel proposition, for it has been discussed for a number of years. It involves a good many questions, some of them going back to the central station. It may be advisable in the end to adopt for alternating-current operation this periodicity, and I ventured months ago to predict that the largest 25-cycle railroad enterprise now carried on would adopt a lower frequency.

In view of the fact that reduction of frequency, which brings a motor more nearly to direct-current conditions, is now acknowledged and advocated as an essential, I find some difficulty in reconciling myself to that subtle reasoning which holds that because a motor is to be run on a part of its route from direct-current supply it is better that it should be designed for the higher frequency.

While in entire sympathy with every practical development, I care not by what means or along what lines, I have opposed, and will continue to oppose any basis of camparison which assumes as worthy of the fullest credence any and every claim made for single-phase alternating motors, while denying either the possibility, practicability, or importance of the utmost development along direct-current lines, whether used for overhead or third-rail construction.

During the last 19 years I have advocated many radical developments on the floor of this Institute, with what results the gentlemen present are familiar. Now, rightly or wrongly, my name is particularly identified with efforts toward higher voltage direct-current operation, even with the third-rail. I willingly accept the sponsorship of that development, and in answer to Mr. Arnold venture to assert that, so far as public sentiment or restrictions are concerned, while it is quite possible that the continued introduction of an exposed top-contact third-rail will be condemned, as it ought to be, it is quite as likely that high-voltage overhead lines, often in close proximity to highway bridges and crossings, and in possibly dangerous proximity to the general public at city terminals, will come under the ban as that a well protected under-contact third-rail will do so.

Further, I will take direct issue with Mr. McClellan, and venture to prophesy that third-rail installations will still proceed with a good deal of regularity.

I am quite sure that many of the critics of the direct-current development are not as familiar as they might be with what has been done in this line within the last year or two, especially in commutating-pole construction and gearless motors. The former, one of my early babies, and now a vital feature in single-phase alternating-current motors, has been reduced to practice with direct-current motors with such success that I fully confirm Mr. Potter's statement as to its efficiency. To my personal knowledge, four-pole motors of this type, varying from 40 to

240 h.p., normal hour capacity, will operate, so far as commutation is concerned, at excess voltages of 75 or 100% with entire freedom from all commutator disturbance. This improvement alone is one of the most remarkable in electric motor construction in recent years; and directly dependent upon it is the possibility of a return to my earlier methods of varying speed and torque of a motor by varying the field-magnet strength, a principle now in common use in variable-speed shunt motors, and which is equally applicable to series machines. This addition of a shunt to the series field has an important bearing upon the comparisons made by Mr. Muralt. The series motor is no longer a machine with a fixed curve, but one with a very wide range of speed and torque control.

In connection with the other important developments, it would be unjust to omit mention of that modest engineer, Mr. Batchelor, who, Columbus-like, by one bold stroke created a departure in gearless machines, individual to direct current work, which is of the utmost importance, and which has received its very practical proof and demonstration, much to the surprise of many critics in this Institute, in the locomotives recently built for the New York Central Railroad.

As most of you are aware, these are gearless machines in which the previously accepted axiomatic principle of fixity of relation between field and armature was abandoned, the latter being mounted directly on the axle, and the fields being carried upon, and as an integral part of, the locomotive frame, supported by its springs and hence moving freely, irrespective of the armature. Not only gears, but armature and axle-bearings are all dispensed with, and the acme of simplicity in motor construction reached. If desired, the armatures of course can also be springborne.

It may interest those who have somewhat cynically questioned 1200-volt direct-current operation, to know that the General Electric, the Westinghouse, and the Electro-Dynamic companies have all either taken, or bid for contracts requiring the use of motors at this potential.

On the matter of standardization, perhaps I can add a few words. To a certain extent some things take care of themselves. The height of a trolley wire is dictated by the necessity of a clear height above a man on a freight car, and is about 22 ft. There can, of course, be considerable variation from this without in any way interfering with actual operation. The location of the third-rail, with center 28.25 in. from the gauge line, and with a working surface from 2.75 in. to 3 in. above the rail, has been practically accepted, as per suggestion sent out a long time ago by Vice-president Wilgus of the New York Central Railroad as chairman of that road's electric commission.

I suppose I ought to feel flattered to see the universal testimony to the benefits of multiple-unit operation; but some of the speakers outdo the parent in love for his child, and have committed themselves to recommendations of an extreme character. Here, too, there is little to be said in the matter of standardization. I settled that nine years ago when I created a train line composed of sections carried upon, and terminating in couplers on each car, and joined by reversible jumpers between the cars—all constructed, connected, and located so that cars could be connected up in any required order, number, or sequence, and indifferently as to end-relation; and the master-controllers connected therewith had like characteristics with reference to track movement. One of the essential features of this train line is the relative location of speed- and direction-controlling wires, the former unchanged in any connection, and the latter reversed in connection when cars are reversed. Would-be improvers departed from the essential five-wire system, abandoned automatic control, and introduced for a time additional individual wires for various rheostatic steps in the speed control, as on the elevated railway in this city; but the progress of events is carrying them all back to the original lines which I laid down. Practical experience, however, leads me to oppose the introduction into a train line of wires for trunk-line connections, heating, lighting, or brake-control.

I am not able to get up any enthusiasm about a proposition to equip the freight cars of the country with train lines. While the control of two distantly placed freight locomotives would at times be useful, it is not vital, nor are there the same reasons which make simultaneous control of motor cars in passenger trains essential.

Certainly no train operation would be conducted without competent men on locomotives which are distantly removed from each other. Moreover, in view of the universal interchange of freight cars, even if the majority of them were equipped with train lines the introduction of a single one without such an equipment would make useless the balance, and the switching necessary to avoid this would be objectionable. The possible advantages of such an equipment are vastly more than offset by the enormous cost.

Calvert Townley (by letter): The tabulation of distributed opertaing costs of steam roads, contrasted with the estimated costs which it is expected will obtain when steam roads shall have been electrified, is interesting, and the conclusions reached are in line with what electrical engineers very generally believe. I am not sanguine that this tabulation will be given material weight by the men whom it is most desirable to convince; namely, the steam railroad operating officials. Such men, as a class, attach, and properly I believe, much greater weight to statistics showing what has been accomplished than to any figures showing what it is expected will be accomplished, no matter how logical these latter figures may be, or with what care and satisfaction to the compiler they may have been prepared. It is also perhaps unfortunate that in the comparison of the operating costs, the authors of the paper should have omitted any figures on fixed charges. Naturally, such charges, resulting as they would from investments needed to electrify, will increase the total expenditures under electric operation, and will act to offset in varying degrees the estimated savings which Messrs. Stillwell and Putnam have taken. To the man who is unable to estimate what will be the investment required to electrify, this may unfortunately be interpreted to indicate a dread on the part of the electrical engineer that a complete comparison of all expenditures for both methods of traction should be made. There is, furthermore, a deeply rooted feeling that the depreciation in electrical equipment due to the replacement of one type by another, so-called amortization, is much higher than is the case with steam equipment, and there is only one way by which such conviction is likely to be removed; that is, by the actual demonstration in practice that the amount chargeable to amortization is small.

With the principle enunciated by Messrs. Stillwell and Putnam on standardization, I am thoroughly and heartily in sympathy; but in the words of an engineer with whom I discussed this matter, I believe we should only undertake standardization when we have something to standardize. Standards are artificial only to a limited degree, and no edict of the Institute, or of any other body, can successfully long maintain a so-called standard against something better, or when greater advantages can be obtained by departing from the avowed standard. I cannot but feel that the Institute would lay itself open to serious criticism if it should undertake, for example, to establish a standard frequency for electrically equipped steam railroads, when there is no single electrified steam road in this country operated by single-phase current. Particularly would this be true if they should adopt a standard different from every single-phase trolley road now in operation, or in process of being equipped in this country, and having as a basis for such adopted standard only the calculations and experiments of the engineers of the manufacturing companies, extending over but a short period of time. The best type of equipment for the electrification of steam roads will ultimately prevail; but it will prevail by practical demonstration as to its fitness, and in no other way. I should regard it as far better that a few railroads should spend some extra money in later changing the equipment which they may have adopted, rather than that some important development in the art should be hampered or prevented because of a decision made now on insufficient evidence. If the authors of this paper should now advise their clients to adopt something which later may be found to be one of the "discards from the deck," they would only have taken a chance which other engineers have taken before, are taking to-day, and must continue to take for some time to come.

With respect to the advantage of 15 cycles or any other modification of a standard frequency that may be suggested, the burden of proof obviously lies with those advocating the change; to receive serious consideration, reasons for the change must be weighty and the evidence supporting them fairly conclusive. In the present instance, the arguments advanced in favor of 15 cycles are essentially two: first, the lower frequency permits a lighter and more compact motor; and secondly, the induction in the line and track are reduced. Of these two reasons, the first is advanced as the controlling one. Every other consideration is confessedly adverse. It is, therefore, pertinent to inquire, in fact we must know, to consider the subject intelligently, how much smaller, lighter, and cheaper the lower-frequency motor is to be. In undertaking to procure this information, however, we are at once confronted with embarrassment. There being no 15-cycle equipments in existence in this country it is not surprising that the Westinghouse engineers hesitate definitely to predict what will be their relative weight, cost, etc., when they shall have been constructed to meet the necessary widely varying specifications that will certainly be forthcoming as soon as the electrification of steam roads is fairly under way.

In considering the electrification of the N.Y.N.H.&H.R.R. Co., plans were submitted by the Westinghouse Elec. & Mfg. Company for both 15- and 25-cycle passenger locomotives. designed to perform identically the same service. Here, then, we have a definite statement of the relative characteristics of the two types applied to a concrete case, and carefully worked out. The figures include, moreover, not only a comparison of motors, where the 15-cycle is lighter, but also of the transformers, where the 15-cycle is heavier, and, further, of the other parts of the locomotive, which are affected variously and in different degrees. It was found that the 15-cycle machine had the advantage of 5.2% in weight, about 3% in cost, and was slightly better as to its efficiency and power-factor. I have been told that the specifications in this cases were not such as to permit full advantage to be taken of possible 15-cycle construction, but the specifications imposed absolutely no limitation in this direction that was not fixed by the operating conditions. I am further advised that there have been subsequent improvements in 15-cycle motor design that now warrant better claims for it, and that in consequence the present difference of weight of locomotives may perhaps be nearly 10%, or, in some cases, and under varying conditions favorable to 15 cycles, even more.

If the locomotive weight may be said to average 30% of the total train weight, the use of a locomotive weighing 5.2% more will add 1.56% to the total train-tonnage. Similarly, ten per cent. increase in locomotive weight will add 3% to the total train-tonnage. In freight service the ratio of locomotive weight to train weight being less, the increase in total tonnage due to additional locomotive weight would be correspondingly smaller. These additional weights, while undoubtedly undesirable, could hardly be considered controlling or as constituting a sufficient offset to the serious objections of a change in standards, even if such change were not coupled, as it is, with the attendant disadvantages to power station construction in lighting, and in the use of auxiliaries of all kinds.

The statement that there have been recent improvements in 15-cycle motor design is interesting as an indication that the last word in single-phase motor design has by no means been said; indeed, it would be a most remarkable condition of affairs and decidedly contrary to the history of every other electrical development were it otherwise, whether the motor be designed for 15 cycles or for any other frequency.

In the light of these facts, with our high-priced prosperity labor and a soaring material market, it is obviously dangerous even to attempt to state the difference which we may reasonably expect will obtain between the cost, for example, of motors of two different frequencies when the dust settles. On this account it appears to me impossible seriously to consider or to attach much weight to the comparative-cost figures presented by Messrs. Stillwell and Putnam for the possible future electrification of the entire railway sytems of the United States.

In this connection it may be proper to point out a future possibility that has not been touched upon, but which may prove to be an important factor in the frequency question. An engineer who has been familiar with trolley practice only, and who studies steam railroad electrification for the first time, may be pardoned if he is surprised as the comparatively small amount of power required by the steam, and he is likely to be further astounded, and perhaps appalled, at the high peaks and wide fluctuations in load. These conditions do not make for the economical generation of power, but on the contrary impose an abnormally heavy fixed charge to cover capital sufficient to handle peak loads, and an unduly large operating cost for the additional force necessary to operate a station to handle peak loads, the average output of which station is, however, but a small per cent. of its capacity. It is possible that Messrs. Stillwell and Putnam had this feature before them in suggesting the distribution of power 150 miles in each direction from centrally located power houses. However, I am not able to justify the general adoption of such a plan, either on the score of expense or of reliability, though there may sometime be found a particularly favorable case where power can be generated from steam and economically transmitted this distance. I am confident, however, that a much smaller initial investment will be required, and a considerably lower operating cost will obtain, if smaller stations are installed at much more frequent intervals. I believe that such a plan will be found more economical, even with the reduced load-factor thereby entailed. But the question of load-factor brings me to the future possibility above referred to, which is this: as soon as the railway manager discovers that in order to make cheap power he must make it in larger quantities than his road can use, and that his station must also have a good load-factor, he will utilize his good railroad credit in the direction of establishing larger power plants than he himself needs, and he will sell quantities of cheap power to neighboring industries, thereby affording them the advantage of such power at lower rates than they could themselves produce it, and securing for himself, not only cheap power for his own use, but a profit on the sale of the surplus.

Twenty-five cycles is a standard and a satisfactory frequency for induction motors in industrial establishments and for synchronous converters where direct-current trolley systems are in operation. Fifteen cycles is likewise applicable to such service but is concededly not so good, and it is not at present a standard. Should it become so, the cost of transformers for use with it will be materially greater than the cost of transformers for 25 cycles—perhaps somewhat in the neighborhood of 40% more, and the frequency is not one that affords as great a flexibility in the speeds of the induction motors supplied by it.

In the light of the foregoing, the following seem to me clear:

1. That it would be wrong to undertake to establish a standard frequency for single-phase railway operation at the present time.

2. That even after it has been credited with all the estimated advantages claimed for it, a 15-cycle frequency has not yet made out a case entitling it to general preference.

Ralph D. Mershon (by letter): It seems to me that we should go slowly in the matter of adopting a standard frequency for traction work. The reasons for caution in this matter are pretty well set forth in the paper, but there is one of the considerations touched upon which will, I believe, before long have considerably more weight than at present. This consideration is that of the use of induction motors for traction purposes, especially motors whose speed characteristics may be varied by a change in the number of poles, In the case of such method of speed-control, a higher frequency than 15 cycles is desirable as giving greater flexibility in the range of speed. It seems to me it would be much better to wait until the lines of development of traction work are more clearly defined than at present before adopting as standard a frequency lower than 25 cycles.

H. M. Brinckerhoff (by letter): The wide field covered by this timely paper and the broad lines on which the authors have laid out their general argument deserves a much more careful analysis and discussion than was possible at the meeting at which it was presented. A brief written contribution, giving some additional data upon some points contained in the paper or referred to in the verbal discussion may therefore not be out of place.

The first of the four points enumerated by the authors: that is, "the record of certain facts relative to heavy electric traction which have been established by experience" brought out in the discussion various references to one of the items that might be further elaborated upon.

The record of the results obtained on the Manhattan Elevated, Subway, and various interurban railways are used as a basis of comparison upon which to estimate operating costs for steam railway electrification. One of the most frequent criticisms offered by steam railway men is that the period of operation of electric installations has been too short to show fully the cost of repairs and renewals, such as are found in similar items in long established steam railroad operation.

The earliest heavy electric railway system is the Metropolitan West Side Elevated Railway in Chicago, which was the first to operate commercially with the third-rail. Starting in April 1895, nearly twelve years ago, it operated with one motor car per train until 1905, then the multiple-unit control was adopted and a second motor car used on four and five car trains, instead of one as previously.

The total cost of operation per car-mile on this road, starting at about $0.075 in 1896-7-8, showed small fluctuations up to 1905, when it was $0.0931, the highest single year being $0.0971 and the average for the ten years $0.0836. Here then we have a system in its tenth year showing a cost per car-mile for all expenses, omitting taxes only, which compares with the steam locomotive operation of the South Side Elevated of Chicago of $0.106, the Lake Street Elevated of $0.1174 and the Manhattan Elevated of New York of $0.1198 per car mile. The increase noted for electric operation on the Metropolitan from 1895 to 1905 is partly accounted for by considerable increases in rates of wages and cost of fuel and general supplies.

As the writer was connected with this road from the start, and general manager for six years prior to 1906, he states on his personal knowledge that the tenth-year costs included renewals in all the items—ties, rails, frogs, and switches, repainting cars, renewals of armatures, commutators, gears, pinions, and all the various items that might be said to have a considerable first life. The fear very naturally entertained at first, that after a certain period the renewals would become excessive, has not been realized, even after a ten years' term of constant heavy service. The costs are greater the tenth year than the first or second, but are still 25% or 30% below corresponding costs of similar steam locomotive operation. At the same time the service has been immensely improved in speed, frequency, and general desirability.

While it is difficult to compare electric car-mile statistics with steam railway train-mile figures, the facts here noted certainly support the contention of Messrs. Stillwell and Putnam for operating costs at least 20% lower for electric than for steam operation under favorable average conditions.

In using the general average results in the carefully prepared tables of statistics presented by the authors, the danger of applying general averages to specific cases should be clearly pointed out. An average is simply the mean value of two or more amounts, and this average value may vary so greatly from some individual figure on the list from which it is derived as to make a specific application based upon it very misleading. General averages are valuable for general broad considerations, but specific cases must be analyzed and determined upon in their individual conditions.

In their estimates of the costs, the authors have assumed the universal use of single-phase alternating-current apparatus. In the discussion at the meeting it was contended that this assumption was too radical, since no single-phase installation of this character has begun actual service. On the other hand, some speakers criticised the idea and use of the third-rail system as out of date. All past experience shows that a radical innovation is not in itself necessarily bad, neither should an existing successfully operating system, whose limitations have been demonstrated under service conditions, be broadly condemned on these points alone. The present existing heavy electric traction systems are the result of development along a line radically differing from the previous lighter forms of street and other railway apparatus, but this has not prevented the enormous extension of the older lighter form in the field for which it is adapted.

As the writer happened to be engaged upon the design of the original third-rail installation for the Intramural Railway at the Columbian Exposition in Chicago during 1892-3, and joint patentee of the various devices then developed, he feels authorized in saying that no claim was then made that *the only true and correct solution of the electric railway problem* had been evolved. Certain conditions had to be met—a light elevated structure of limited dimensions and clearances, trains of four cars to carry dense passenger traffic, with stations close together, and demands for the highest possible speed and regularity of operation.

This problem was then absolutely new. That the system was evolved, the apparatus designed, installed, and put in operation in less than eight months, and fourteen four-car trains on a line about three miles long, carried successfully from 100,000 to 125,000 passengers in days of 14 to 15 consecutive hours, does not call for any apologies from those connected with this work.

The use of the third-rail itself was brought about by the necessity for collecting large amounts of electric current from a stationary conductor by apparatus attached to moving cars. The decision to use a large cast-iron shoe sliding on a steel rail was met with many predictions of failure; the result is a matter of history.

The problem met in 1893 is presented to-day, changed only in magnitude. The solution then evolved accomplished its purpose so successfully that in the year 1906 the third-rail system of the U. S. hauled close upon 700,000,000 passengers, at a cost fully 20% below what it would have been with steam.

The writer does not wish to be understood as advocating the whole sale installation of the third-rail on all the steam railway systems of the United States. It has a field, however, of its own which it is occupying successfully. That it has been found to have objectionable features in certain cases is not surprising; on the contrary the variety of conditions which it has successfully met is rather remarkable.

When we discuss the broad problem of electrifying transcontinental railway systems, the added magnitude of the problem involves the further conditions of great distances and large and infrequent train units. The obvious course to pursue under such conditions is to raise the voltage on the working conductor, and that this involves overhead contact is very apparent.

In examining the many forms of alternating-current single- and three-phase lines in Europe last winter, the writer could not but help noting a number of details which are pertinent to this discussion. The use of the relatively high-voltage trolley is successfully accomplished and the insulation of the high-tension-side of the apparatus on the car is not seriously troublesome. It is also true that a system like the Valtellina Line in northern Italy performs all the functions of a steam railway system. Trains of through freight, local freight, express passenger trains, local passenger trains, excursion and specials are run, with interchange of cars and traffic, with the steam railway systems of the country.

There are some points upon which we must be on our guard, however, in making comparisons. Continental railway roadbeds are very superior, as a rule, to the average in America, nor have they the immense and complicated freight-yard layouts and intricate switching problems seen on our lines. The cars are much lower and very light compared with our freight, passenger, and Pullman cars. Wages are much lower and the demand of the public as to quality of service not so severe.

All these must be allowed for in using their cost figures. What they have accomplished in various lines is very instructive and interesting, and it is flattering to know that the incentive vigorously to develop single-phase railway equipments now being pushed by some of the largest firms in Europe came from reports of American effort in this line.

The authors' third point: " Importance of Standardizing Electrical Railway equipment as rapidly as may be consistent with progress " is certainly timely and well taken. Upon the assumption of ultimate universal electrification of the entire railway systems of the country, it is well to note that the interchangeability at present effective on the steam railways does not mean actual identity of apparatus, but sufficient similarity to insure coupling, hauling, heating, and renewal of parts such as journal brasses, etc., upon all lines.

As there is now a variety of types of locomotives on connecting systems and these are operated, generally speaking, on their own lines, so it should be possible to operate through passenger and freight business entirely by standardizing the few items mentioned, and yet retain the advantages of motive power apparatus of different types specially suited to meet certain local conditions.

The great flexibility thus far shown in the development of electric railway apparatus, such as the use of the third rail on private right-of-way and overhead trolley upon streets; and running alternating current on one part and direct current on other parts of a line with the same cars, are only indications of the possible interchangeability of systems of apparently hopelessly divergent characteristics. The two classes, freight and heavy Pullman or passenger cars, are, broadly speaking, the through equipment. On neither of these is it likely to be found desirable or economical to install individual motor equipment and multiple-unit control. The local and suburban trains, with multiple-unit control, will not leave the parent system. Interchangeability then of the *through equipment* does not prevent the selection locally of the most desirable motive power system, provided the present degree of standardization common in steam railway practice is adhered to.

During the present period of development and adjustment of electric traction to steam railroad conditions, the existence and advocacy of different types of apparatus brings to the problem a spirit of emulation and competition that is tending to greater perfection of detail and much more rapid progress than would be the case were all engineers working on a single type. The fact of honest difference of opinion by men striving to meet certain specific conditions successfully is not a sign of weakness as some doubters would have us believe, but a strong argument for the broad applicability of electric power.

A. H. Babcock (by letter): The salient points of the paper seem to me to be the statement that the alternating-current equipment is the only class of equipment deserving serious consideration in connection with the general problem of heavy traction. the question, " where ten years from to-day, will be the 1200-volt of 1500-volt direct-current system? " and the plea for standardization of 15-cycle apparatus.

It is to be regretted that at present there is not available any detailed information covering the actual operating data (such as follows) on the few single-phase roads now in operation. In one of the cases that has come under my personal notice, three passenger cars and two work cars are operated. The passenger cars are equipped with from 100 h.p. motors and weight equipped, but not loaded, 40 tons. The work cars have four h.p. motor equipments and weigh somewhat less. Power is purchased at three phase 60 cycles, is converted to single phase 25 cycles, is metered and paid for at the rate of 1¼ cents on the three-phase side of the converting set. Measured here, the following figures were obtained for one month's operation last fall.

Average tonnage per car operated	36.25
" watt-hours per ton-mile	153
" cost of energy per car-mile	6.92 cents.
" kilowatt-hours per passenger car-mile	6.12
" cost of energy per passenger car-mile	7.65 cents.

It should be noted that the foregoing figures are for power alone, without any fixed charges or other expense. With a total of five cars of all kinds under operation, eight men including the foreman, were needed and employed in the car house on motor-car repairs, with two more men available for emergencies.

Is this sort of thing " the only class of equipment deserving serious consideration in connection with the general problem which we are discussing? "

If this road had been equipped with 1200-volt direct current, under the same operating conditions and losses in transmission as are now made, the energy per ton-mile would have been 107 watt-hours as against the 153 actually recorded, and the monthly cost of energy would have been reduced in proportion.

It is safe to say that the 1200-volt or the 1500-volt direct-current system will be heard of in ten years, if the single-phase system is not developed far beyond the inefficient case cited above.

With reference to standardizing 15 cycles, it may be remembered that the first installation proposed called for 16⅔ cycles. Afterward 25 cycles was made the standard in order to fit existing apparatus, and we were informed that the change in frequency made no difference. Now we are informed with equal positiveness that 15 cycles is to be the panacea, and this in spite of the fact that not one 15-cycle installation is in operation in this country. An engineer responsible for the expenditure of large sums of money may well hesitate about standardizing anything in a field where the very first development has yet to be made and proved.

It is not my intention to appear to condemn the entire single phase system on the showing of the one road the operating costs of which have been investigated by me; nor is the fact that 1200-volt direct-current motors have been specified by me for a large suburban service to be taken as a declaration in favor of high-voltage direct-current as a substitute for single-phase in all cases. The right is reserved to choose for every specific case the type of apparatus best adapted.

All engineers in a similar position must regret the absence of published accurate disinterested information on the operating costs of the few single-phase roads now in operation.

W. S. Murray (by letter): Upon the belief that the two departments in which the greatest economies to be derived in electric versus steam operated trains are fuel and locomotive repairs, it has been my effort during the past eighteen months to secure absolutely reliable data in these two departments of cost concerning the steam operated trains of the New York Division of the New York, New Haven, and Hartford Railroad Company.

FUEL.

Ton-miles are produced in several classes of service, viz:

1. Passenger express.
2. Passenger express-local.
3. Passenger local.
4. Freight.

Table 1.—Express Passenger Service.

No. of Locomotive.	Mileage of locomotive in 18 days.	Pounds of coal burned in 18 days.	Average weight of train, including locomotive and passengers.	Total ton-miles of train, including locomotive, passengers, and switching for 18 days.	Total horse-power-hours for 18 days of locomotive in revenue service based on average h.p. between Woodlawn and New Haven.	Pounds of coal per indicated h.p.-hour based on average indicated h.p. between Woodlawn and New Haven.	Total revenue ton-miles of train, including passengers and locomotive for 18 days.	Pounds coal per revenue ton-mile.	Pounds coal per indicated h.p.-hou- by average ton-mile method.
832	2,782	301,384	573.5	1,556,730	73,100	4.12	1,545,000	0.195	4.40
841	2,336	215,830	480.7	1,123,050	53,150	4.06	1,123,000	0.192	4.34
Avg.	2,559	258,607	527.1	1,339,890	63,125	4.06	1,334,000	0.194	4.37

Local Express Passenger Service.

1262	3,160	295,038	303.0	914,330	63,900	4.62	894,000	0.330	4.54
1258	2,644	264,138	302.2	795,182	57,000	4.64	794,500	0.330	4.54
1272	3,482	353,396	351.5	1,147,520	80,000	4.42	1,114,000	0.317	4.36
1571	1,890	187,180	307.8	577,929	40,600	4.61	566,000	0.331	4.55
1574	1,938	216,583	306.4	593,838	42,500	5.10	593,000	0.366	5.04
Average	2,623	263,267	314.2	805,760	56,800	4.68	792,300	0.335	4.61

An interesting and valuable query is, what fraction of a pound of coal is consumed in producing a ton-mile in any one of the above services? Tables 1 and 2, following, show that it takes 0.169 lb. of coal, 0.194 lb. of coal, and 0.335 lb. of coal to produce a ton-mile in freight, express passenger, and express local passenger service, respectively.

It will be further noted that in the above tables there is given the pounds of coal required per indicated horse power hour for the passenger service. The ten heads under which the compilation of these tables were made show, in order that these data be absolutely reliable, the following conditions must be satisfied:

1. Exact mileages measured.
2. Exact weight of tonnage hauled.
3. Exact weight of coal burned.
4. Maximum continuous number of indicator diagrams taken to determine indicated horse power.
5. A sufficient number of days of continuous test to assure average results.

1. *Exact Mileages Measured.* The zone over which the test was conducted was the New York Division of the N. Y. N. H. & H. R.R. Co. and all trains runs had specified terminals within the zone, the mileages of whch are measured.

2. *Exact Weight of Tonnage Hauled.* The engines, twenty in number, and all cars included in the test were in the regular log of the mechanical superintendent and the superintendent of car service, with measured weights.

TABLE 2.—FREIGHT SERVICE.

No. of Locomotive	Mileage of locomotive in 18 days	Pounds of coal burned in 18 days	Average weight of train, including locomotive	Total ton-miles of train, including locomotive, for 18 days	Pounds of coal per ton-mile
300..........	1,557	230,376	930	1,446,868	0.159
301..........	1,153	184,836	661	761,755	0.242
325..........	1,592	231,366	696	1,108,615	0.209
373..........	2,010	237,006	1,060	2,129,575	0.111
382..........	2,018	304,044	1,240	2,495,072	0.122
386..........	1,274	220,680	731	930,792	0.237
448..........	2,272	413,106	1,255	2,850,046	0.145
453..........	2,350	255,444	872	2,053,142	0.124
Average......	1,778	259,607	931	1,721,983	0.169

3. *Exact Weight of Coal Burned.* Each of the twenty engines coaled from an individual car, the weight of the coal therein being measured immediately before and after the test, the coal cars being placed at the regular coaling points of the locomotives.

4. *Maximum Continuous Number of Indicator Diagrams Taken to Determine Indicated Horse Power.* A continuous set of indicator diagrams were taken on a locomotive for both express and express local runs between Woodlawn and New Haven. A wind-shield was erected over the left cylinder of the locomotive, and the following scheme of indication adopted, viz:

a. One minute allowed for changing cards on steam indicator.

b. Six diagrams per minute to be taken on the same card.

c. Two minutes to be devoted to taking cards.

d. Interval between cards, twenty seconds.

It will be noted that by this method on each indicator card there were obtained twelve indicator diagrams; six for each end of the cylinder. The average mean effective pressure of these cards was taken to secure the indicated horse power for the cycle of three minutes above described. This three-minute cycle of 66% card indication, was practised several days until perfect runs were obtained between Woodlawn and New Haven, east and west. Then five continuous east and west runs were made for both express and express local service, and an average indicated horse power per ton for each class of service was obtained. By this method of continuous indication throughout all parts of the division, both east and west, the results would seem to be accurate.

5. *A Sufficient Number of days of Continuous Test to Secure Accurate Results.* Eighteen days were considered sufficient.

TABLE 3.

	Ton-miles per annum	Tons of coal steam traction	Tons of coal electric traction	Cost of coal steam traction	Cost of coal electric traction	Saving of electric over steam traction
Express...	592,240,000	57,447	29,870	$183,830	$89,620	$94,210
Express loc	348,000,000	58,300	28,600	186,560	85,800	100,760
Express frt	2,223,000,000	187,844	139,010	563,530	417,030	146,500
						$341,470

The test was conducted during the month of August. The track and temperature were favorable to steam locomotive traction.

Table 3 shows the relative amounts of coal required for electric *vs* steam locomotive traction. In the former case the coal as measured in the electric power house; in the latter as measured in the fire-boxes of the locomotives. The cost-item is interesting in this table, indicating that the New York Division when operated by electricity will show a saving by coal alone of $341,470.00 per annum.

It is to be noted that the pounds of coal per indicated horse power hour is not simply the weight of coal used to accomplish an individual engine run, but the weight used in an all-day service of 24 hours, which includes the time the engine is idle. As the engines are indicated for a given revenue run, this weight of coal might be well termed: The pounds of coal per revenue indicated horse power hour.

b. Locomotive Repairs. Table 4 is a typical sheet showing the scheme of accounts kept on each of the twenty locomotives for a period of one year. The sheets selected are those showing the maximum and minimum months for freight and passenger engines.

TABLE 5.

		Mileage made by locomotive	Total cost of repairs in $	Cost of repairs per mile in cents.	Total cost of maintenance in $	Total cost of maintenance per mile in $	Total cost of repairs and maintenance per mile in cents
FREIGHT	Aug. '06	22,342	1323.	5.92	292.	1.31	7.23
	July '06	22,843	1140.	4.99	257.	1.12	6.11
	June '06	26,570	920.	3.46	326.	1.23	4.69
	May '06	32,678	825.	2.52	451.	1.38	3.90
	Apr. '06	22,500	438.	1.95	367.	1.63	3.58
	Mar. '06	24,984	351.	1.40	335.	1.34	2.74
	Feb. '06	24,788	1254.	5.05	353.	1.42	6.47
	Jan. '06	29,848	5150.	17.26	433.	1.45	18.71
	Dec. '05	24,017	2961.	12.33	362.	1.51	13.84
	Nov. '05	29,528	2029.	6.87	455.	1.54	8.41
	Oct. '05	19,523	2050.	10.50	305.	1.56	12.06
	Sept. '05	19,825	1568.	7.91	320.	1.61	9.52
	Total...	299,446	20009.	80.16	4256.	17.10	97.26
	Average per mile...		6.68	6.68	1.42	1.42	8.10
PASSENGER	Aug. '06	32,409	2674.	8.25	638.	1.96	10.21
	July '06	32,199	373.	1.15	561.	1.74	2.89
	June '06	35,272	612.	1.74	583.	1.65	3.39
	May '06	34,833	5129.	14.70	674.	1.93	16.63
	Apr. '06	31,395	429.	1.37	554.	1.77	3.14
	Mar. '06	33,332	743.	2.23	575.	1.72	3.95
	Feb. '06	26,428	1040.	3.93	475.	1.76	5.69
	Jan. '06	37,008	385.	1.04	637.	1.72	2.76
	Dec. '05	31,977	830.	2.63	552.	1.73	4.36
	Nov. '05	43,485	1338.	3.08	681.	1.56	4.64
	Oct. '05	37,394	1172.	3.13	615.	1.65	4.78
	Sept. '05	41,304	1376.	3.33	621.	1.50	4.83
	Total...	417,036	16121.	46.58	7166.	20.69	67.27
	Average per mile...		3.88	3.88	1.72	1.72	5.60

Table 5 is a complete compilation of the twelve months of locomotive repairs and maintenance.

This investigation leads me to the two following conclusions:

1. For a mixed freight and passenger service the same gross draw-bar can be produced by the single-phase method of traction for 60% of the coal required by the steam method of traction.

2. Locomotive repairs are between three and four times as great for steam as for electric locomotives.

L. B. Stillwell and H. S. Putnam (by letter). The paper which we had the honor to present at the two hundred and thirteenth meeting of the American Institute of Electrical Engineers, as stated in its first paragraph, had four objects. 1, To record certain facts relative to heavy electric traction which had been established by experience; 2, to present calculations of relative costs of steam and electric traction in railway service based upon these facts; 3, to point out the transcendent importance of standardizing electric railway traction equipment as rapidly as may be consistent with progress; and 4, to raise the question whether a frequency of 25 cycles per second or 15-cycles per second should be adopted in railway operation by alternating-current motors.

Our purpose in working out and presenting detailed calculations of relative costs of operation by the steam locomotive and the single-phase motor was to secure for ourselves and others a comprehensive view of the great problem which railway engineers to-day are called upon to consider—a comprehensive view being obviously a requisite first step toward an adequate and satisfactory general solution. To realize the magnitude of the problem and the advantages in respect to increased earnings and decreased operating costs which in general will result from the substitution of the motor for the steam locomotive, is to recognize the fact that railways are destined to use electricity upon a scale which demands a general solution and to appreciate the importance of prompt standardization of the frequency chosen for alternating-current work.

While expressing the belief, that as compared with 25-cycles "a frequency of 15-cycles is preferable and should be adopted for heavy electric traction," we stated that our object was rather to present the question of frequency for discussion than to advocate the adoption of any particular frequency, and we suggested a careful consideration of this very important question by the Institute through its Standardization Committee or a special committee.

The oral discussion which followed the presentation of the paper was conclusive, beyond our expectation, as regards frequency. So far as the general practice of engineers who may adopt the single-phase alternating current is concerned, we regard the matter as practically settled by the facts and opinions brought out by the discussion. The designing engineers of both the Westinghouse and General Electric companies testified emphatically to the great increase in power of motors which can be realized by reducing the frequency, and while several speakers questioned the wisdom of now adopting a standard, no one came forward to argue that the higher frequency is preferable.

Mr. Lamme to whom, more than to any other man, we owe the single-phase motor, stated that at 15 cycles the output of a given motor is from 25% to 40% greater than at 25 cycles and that his company had verified this by actual test.

Mr. Storer testified that:

> You can get at least 30% greater output from motors with 15 cycles than with 25 cycles.

Mr. Slichter, the engineer of the General Electric Company, who has immediate charge of the work of designing single-phase motors, said:

> There seems to be a unanimous opinion that the output of the motor may be increased some 30 to 35% by a decrease in frequency from 25 to 15 cycles.

Mr. Potter, chief engineer of the railway department of the General Electric Company, after pointing out some of the difficulties in the way of the adoption of 15 cycles, said:

> I do not think, however, that we can look for the ultimate development of the single-phase motor of 25 cycles.

In his written contribution to the discussion of the paper, Mr. Frank J. Sprague says:

> It may be advisable in the end to adopt for alternating-current operation about this periodicity, and months ago I ventured to predict that the largest 25-cycle railroad enterprise now being installed would adopt a lower frequency.

Mr. Calvert Townley alone, among all who have orally or by written communication discussed the paper, advances arguments in favor of 25 cycles, but even in this case the position taken is one advocating suspension of judgment rather than asserting superiority of 25 cycles, as is shown in the following statement with which he concludes his letter:

> In the light of the foregoing the following seem to me clear:
>
> 1. That it would be wrong to establish a standard frequency for single-phase railway operation at the present time.
> 2. That even after it has been credited with all the estimated advantages claimed for it, a 15-cycle frequency has not yet made out a case entitling it to general preference.

The paper and the discussion have established the fact that the increase in cost of the power-house equipment consequent upon the suggested reduction in frequency is far more than offset by the reduction in cost of electric equipment of rolling stock consequent upon the adoption of 15 cycles.

As regards power-house and sub-station cost, we estimated that the difference in favor of the higher frequency is about $10,000,000, assuming that all the American railroads now operated by steam should adopt electricity.

As regards cost of the electric locomotives, Mr. Storer stated that the difference in favor of the lower frequency would approximate $5,000 per locomotive. In naming this figure, doubtless he had in mind the present cost of electric locomotives, while in our estimates we have assumed that this cost, which is now approximately $30,000, will be reduced to $25,000. Making a corresponding reduction in Mr. Storer's estimate, it appears that the saving per locomotive, in the opinion of the chief engineer of the railway department of the Westinghouse Electric & Manufacturing Company, will approximate $4,000 in favor of the lower frequency.

The question whether 24,000 electric locomotives would do the work of approximately twice that number of steam locomotives now owned by the railroad companies is certainly open to discussion. If the actual number required be greater than the number assumed, the argument in favor of the lower frequency is strengthened. In our paper we expressed the opinion that work equivalent to that now done by approximately 48,000 steam locomotives could be performed by electric locomotives numbering from one-half to two-thirds of that figure, and in showing that the change to the lower frequency would effect a saving in first cost of aggregate equipment we used the smaller figure in order to be entirely fair to the higher frequency. Adhering to the figure, 24,000, as representing the aggregate of electric locomotives required, and taking Mr. Storer's figure of $4,000 as representing the difference in cost per locomotive, it appears that while the adoption of the lower frequency would involve an increase of about $10,000,000 in cost of power-house and sub-station equipment, it would save $96,000,000 in cost of rolling stock equipment; both of these figures having reference to equipment of the entire existing railroad systems of the United States. The point made by Mr. Storer, therefore, greatly strengthens the argument in favor of the lower frequency.

The practical unanimity of competent opinion evidenced in respect to the advantages of the lower frequency, and the fact that practically every American designing engineer who has participated actively in the development of single-phase railway apparatus was present and joined in the oral discussion, would seem to have established definitely and finally the wisdom of adopting the lower frequency. It is possible that special cases may arise in which local conditions are sufficient in weight to justify the use of the higher frequency, but it is perfectly clear that hereafter the engineer who in single-phase alternating-current railway work adopts 25 cycles will accept serious responsibility and should be able to base his decisions upon concrete and local factors such as will be found to exist in very few cases.

The fact that the Oerlikon Company, of Switzerland, and the Siemens-Schuckert Company, of Germany, in manufacturing single-phase motors of the type adopted by the Westinghouse and General Electric companies are adopting 15 cycles, is an interesting point presented by Mr. Lamme and is excellent evidence in favor of the lower frequency.

Aside from the interesting discussion of the question of frequency, the paper has resulted in the presentation of certain facts of material value and of numerous opinions, many of which deserve respectful consideration. Among the facts of special value may be mentioned the data presented by Messrs. Lamme and Potter relative to comparative slip of wheels at 15 and 25 cycles. It is highly desirable, however, that these facts be supplemented by further experimental determinations. Mr. W. S. Murray has contributed data of especial value in the shape of costs of steam locomotive operation on the New York, New Haven and Hartford Railroad, these costs being in certain respects analyzed more thoroughly than is usual in the locomotive performance records of our steam railroads. Mr. Slichter's figures showing how the cost of electric equipment in certain cases would be affected by the suggested change in frequency, are of particular interest. Mr. de Muralt's discussion of certain comparative characteristics of single-phase, three-phase and direct-current motors is also of value. It is to be regretted that the comparative merits of the two frequencies under consideration were not discussed from the standpoint of the induction motor. The point was referred to in our paper, and Mr. Ralph D. Mershon in his printed communication expresses the opinion that in the near future this consideration will have greater weight than is now generally recognized. It is certainly desirable to have additional light upon this aspect of the subject, and it is to be hoped that if the advocates of the induction motor for traction purposes have in their possession any facts of importance not yet published they will see their way to present such facts at an early date.

Aside from the discussion of the question of frequency and the presentation of test data, the oral discussion and the written communications subsequently contributed bring out the following facts:

1. That Mr. Frank J. Sprague, and possibly a few other engineers, are inclined to believe that the high-potential direct-current motor, (for example, 1200 or 1500 volts) is perferable to the single-phase motor.
2. That a considerable number of engineers feel that the time to standardize has not yet arrived.

Such advantages as the direct-current motor possesses in the general railway field disappear rapidly when we consider this field as a whole rather than regard special cases in which the reasons for electrification are so weighty as to overcome even the comparative disadvantages of a system apparently limited to 1200 or 1500 volts, and necessarily limited by the interposition of synchronous converters between generators and motors no matter what the ultimate voltage for which direct-current motors may be designed. They also shrink materially when we compare the direct-current motor with the 15-cycle motor instead of the 25-cycle motor.

In the course of the discussion, Mr. Sprague made the following interesting statement:

> I am going to make a prophecy—that on a large number of lines which can by any stretch of imagination be considered as subject to a reasonable prospect of electrification, that 1200 or 1500 volts will on, any present development known, give better results in every way than the alternating-current 15- or 25-cycle overhead system.

It is to be hoped that Mr. Sprague will present facts and figures upon which this interesting prophecy is based. Meantime, however, it may be pointed out that he limits the alleged superiority of the direct-current system to:

> A large number of the lines which can, by any stretch of imagination, be considered as subject to a reasonable prospect of electrification.

The imagination of one man may stretch more than that of another, and in effect Mr. Sprague proposes the plan of special solution. The growth of traffic will constantly operate to bring roads now outside what he considers the practicable field, within that field. Obviously, it will not do to treat this problem as limited to roads having to-day certain density of traffic or limitations of length which may enable the direct-current system to make a good showing. Problems which ten years ago were on the remote horizon are solved and behind us, while problems which twenty years ago were regarded only by the poet are now in the hands of the operating superintendent.

The position which we take in this matter may be stated as follows:

a. A general view of the railway field, including freight as well as passenger traffic, obviously shows that for anything approximating a general solution the single-phase alternating-current system is decidedly superior to the 1200- or 1500-volt direct-current system. This conclusion is corroborated by calculations easily made and based only upon established facts.

b. The admitted advantages of electricity in respect to increased earning power and decreased cost of operation are such as in the near future assure rapid increase in the use of electricity by railway systems now operated by steam.

c. The necessity of standardizing frequency rests practically, although less directly, upon the same arguments as have induced railways to standardize track-gauge, height of draw-bar, location and couplings of air brake, train-line, and steam-line.

In other words, the significance of our estimates of comparative operating costs is that the results, viewed in connection with admitted facts in respect to increased earnings, indicate that a general electrification of important railway divisions, and even of trunk lines, is coming much more rapidly than has been realized, even by electrical engineers; and the lesson to be drawn from this conclusion is that we must standardize as promptly as possible everything essential to convenient interchange of rolling stock.

As regards multiple-unit control equipment, to which Mr. Sprague refers, it will be absolutely necessary to standardize this, at least so far as the train-line connection is concerned, if the time should arrive when freight trains are to be operated by electric locomotives located at intervals throughout the train. Undoubtedly this possibility now appears remote, by reason of the fact that it would call for a general equipment of the freight cars used by all railways in the United States. It is precisely by this method, however, that the greatest possible advantages of electrification might be obtained. The enormous gain resulting from the ability to operate freight trains of any desired length without increasing the strain on draft-gear, and by a system permitting instant and effective train control at the will of the motorman on the leading locomotive, is obvious to every railway engineer or operator; and it is probable that in no other way could the ability of some of our trunk lines to handle the freight traffic which to-day is overcrowding their existing track facilities be more economically increased. Not many years ago railway operators, in general, regarded the proposition that freight cars be supplied with air-brake equipment as an impracticable dream; to-day the supposed dream is a reality in respect to more than 85 per cent. of this class of rolling-stock equipment. Similarly the idea of equipping all cars with automatic couplers was opposed as impracticable, but to-day such couplers are in general use. In view of these facts, and of the enormously valuable results which might be attained in the case of many trunk lines by employing the multiple-unit system, we contend that the argument in favor of the selection of a standard system of electric supply for railway operation is materially reinforced by the possibility that multiple-unit control may be used in the not very distant future in the operation of freight trains.

It is suprising to find Mr. Armstrong and a few other engineers opposing the idea of standardizing ordinary railway practice. The explanation of their attitude must be found either in the fact that they have inferred more than was intended by our use of the word "standardization," or that they have failed to realize an adequate general view of the railway problem which confronts electrical engineers.

Our paper proposed that standards of practice be agreed upon in respect to: *a*, location of third rail; *b*, location of overhead conductor used with single-phase alternating-current systems; *c*, frequency of alternating traction systems. We remark also that it is clearly desirable but probably less easy to agree upon a standard system of multiple-unit control for train operation.

As reported in the stenographic notes of the discussion, Mr. Armstrong said:

> It is not a case of types of apparatus, or a question of frequency. Each case has to be considered by itself. In ten years from now we will still be disputing over the question of frequency, alternating-current or

direct-current operation. Looking back on the history of the steam locomotive, we have no standard. You can talk to the representatives of the different roads, the master mechanics and different engineers, and they have their own ideas about various matters in connection with their locomotives, * * *

Undoubtedly ten years from now the master mechanics and engineers of electrically operated railroads will still have their own ideas about various matters in connection with their locomotives. As regards all things essential to interchange of rolling stock, however, it is safe to assume that practice will be uniform; and the earlier uniformity is attained, provided that system best fitted to survive is selected, the better for all concerned.

The question whether it be wise or unwise now to agree to set aside as inadequate for the solution of the general railroad problem all direct-current systems, depends upon the question whether we now possess adequate knowledge of the possibilities and limitations of the contrasted systems. It is our contention that such knowledge is now available.

In 1890 the standard frequency of 60 cycles was chosen for lighting purposes. This choice was based upon knowledge certainly not more complete in respect to the requirements of the field of use, and the limitations and possibilities of apparatus applicable thereto, than is now available to enable us to make a wise choice of frequency for railway apparatus. In 1890, 60 cycles was not a case of the survival of the fittest. As a matter of fact, when it was chosen as the standard frequency to supersede the higher frequencies previously in use, it had never been embodied in a commercial plant in actual operation. Nevertheless it appears to have withstood successfully the test of time.

Similarly in 1890 the Westinghouse company selected as standard for work in which synchronous converters were to be employed extensively, the frequency for 30-cycles. About two years later, and before any important plants using 30-cycles had been installed, this was changed to 25-cycles, owing primarily to the fact that the Niagara Falls Power Company had arranged to install turbines operating at 250 rev. per min.—a speed which did not permit the development of 30-cycle current by alternators directly connected to the turbine shafts.

The frequency, 25 cycles, when adopted for the Niagara installation, was not selected as the survival of the fittest among a number of alternative frequencies preferred by various engineers and experimented with in commercial service at the expense of the purchaser. At the time it was chosen, knowledge of the facts essential to a wise choice was far less exact and comprehensive than to-day is our knowledge of the considerations which should enable us to predetermine and select that frequency which is best fitted to survive in railway service.

In his exceptionally valuable contribution to the discussion, Mr. H. M. Brinckerhoff takes the position that the essential condition of interchangeability of through equipment does not prevent the selection, locally, of a variety of motive power systems:

Provided the present degree of standardization common in steam railway practice is adhered to.

The question is very important, and it is a fortunate fact that electric rolling-stock equipment offers many interesting possibilities of operation over lines supplied with electric motive power of various types. Such operation, however, as illustrated by the equipment of the New York, New Haven and Hartford Railroad, which is adapted not only to the 11,000-volt single-phase overhead system chosen by that company, but also to the direct-current third-rail system of supply used in the Forty-second Street terminal, implies, necessarily, a degree of complication expensive, and, from the operating standpoint, very undesirable.

If some of our railways are to use 6,600-volt overhead trolley systems of supply, others 11,000-volt systems, still others 1,500-volt direct-current systems, 600-volt third-rail systems, and any other systems which ingenuity can suggest, no conceivable complication of rolling stock equipment will permit operation of motive-power units over the railway lines of the country as a whole.

As regards the necessity of standardization in order to avoid confusion and loss as the zones of electrification of our railway systems are extended, the following considerations, not specifically mentioned in the paper or in the discussion, and apparently overlooked by some who have discussed our paper, may be referred to:

1. The effect of consolidations. The doctrine of special treatment of individual cases of electrification now presented to the electrical engineer, if adopted, will lead to needless expense and great inconvenience in operation in cases where properties equipped with different systems may be consolidated at some future date. The same is true in case of a transfer or sale of a section of line by one railroad property to another.

2. In emergency, in case of accidents blocking the line, our steam railways not infrequently send their trains to destinations by using lines belonging to neighboring railways under different management. If one line is to use the 1200-volt direct-current system, and another the alternating-current system, such accommodation will be impossible.

3. At junction points and terminals the use of different systems in permitting interchange of rolling stock is in many cases practically prohibitive. Every terminal in the city of Chicago is in use by two or more trunk-line railways, and in such a case as this obviously uniformity of systems, frequency, etc., is essential.

It appears unnecessary to elucidate further the reasons which from an operating standpoint argue so strongly against the idea of special solutions of individual cases. Every experienced railway man will recognize their force without argument.

It has been suggested that the adoption of a standard system of supply for railway lines may retard progress by limiting, or checking, the spirit of emulation and competition of inventors and engineers. This question, it will be noted, is not raised by our suggestion that the frequency, 15-cycles, be adopted as a standard for alternating-current railway work. Obviously the opportunities for improvement and development are quite as great at 15 cycles as they would be at 25 cycles.

The question is pertinently raised by our expressed opinion, that for a general solution of the broad problem of railway electrification only alternating-current systems are deserving of serious consideration, and those who believe that direct-current systems may be capable of development to a point which will make them, or one of them, effective and satisfactory for the solution of the general problem, are justified in making the point referred to. For ourselves, the arguments in favor of the alternating-current system are such as justify the setting aside of direct-current systems and concentration of effort in the prompt standardization and more rapid development of the alternating-current system, which, by its essential characteristics, is obviously best adapted to the solution of the general problem.

It is pointed out that the existence of a certain number of 25-cycle generating plants, sometimes owned by the railway, and possibly available as a source of power supply for emergencies, is a consideration of weight in some instances. The answer to this is that undoubtedly in each specific case of contemplated electric installation the problem should be carefully studied with reference to local as well as to more general considerations, and it is not impossible that in some cases the weight of local considerations may justify departure from the general standard. This obvious fact, however, does not argue against the general adoption of a standard. So far as it has weight, undoubtedly it argues in favor of 25 cycles, but it in no way supports the position, which some have taken in opposition to our contention, that a standard should be promptly agreed upon.

One or two contributers to the discussion have criticised our use of the *Statistics of Railways*, issued by the Interstate Commerce Commission, on the ground that these reports are not reliable. For our purposes and as used by us they are, on the contrary, entirely adequate and convincing. The fact that they are not complete in detail does not materially affect their value for our purposes, as we are dealing with the ratio of the individual items to the total operating expense. Obviously, the ratio of saving indicated by our calculations cannnot be applied to individual roads indiscriminately. It could be so applied only to a railway which might happen to represent exact average conditions. It is hardly necessary to explain that the management of any railroad contemplating the adoption of electricity must study the problem with reference to its detailed and carefully analyzed conditions and costs of operation. In attempting to fix comparative costs of the various items of operating expenses, moreover, we have used not only the reports of the Interstate Commerce Commission, but the annual published reports of many railroads and also detailed unpublished reports kindly furnished by officials of the Pennsylvania, the Erie, Missouri Pacific, Denver and Rio Grande, and other railroad companies.

One or two critics have considered it unfortunate that, in connection with our calculations of comparative operating costs, we did not include an estimate of the capital charges involved in the case of electric equipment. This omission was deliberate. To include capital charges is in no way essential to the purposes of our paper, and to do so would raise questions tending to divert attention from the object which we had in view. For example, the treatment of the question of "depreciation" is one which might well become the subject of a paper of considerable length, and the methods of financing railroads in America are so far from having attained a standard of practice that we have deemed it best to show only the calculated saving in operating costs per mile of line as compared with interest on the cost of required electric equipment, exclusive of rolling stock.

Several gentlemen who discussed the paper expressed the opinion that, while the apparent reduction in operating costs, as shown by our analysis, is 18% (exclusive, of course, of capital charges), roads in general will not make the change in order to effect this economy, but will be influenced to a much greater extent by the increased earning power resulting from the change. This consideration is not new to the authors. One of them recalls pointing it out to the president of the Manhattan Railway Company some ten years ago.

The results of our estimates, in which we have endeavored to compare the operating expenses under a system of electric traction with the actual grand averages of operating expenses throughout the United States, are more favorable to electric traction than we had anticipated when this work was undertaken, but it is hardly necessary to point out that no competent engineer would infer from these results that every railway in the United States is likely to be electrified in the immediate future. The possible economies effected by such substitution, however, when considered in connection with the increase in earning power to be anticipated, leads to the conclusion that the electrification of our railways is destined to be carried on much more rapidly than is realized to-day by the average engineer, and emphasizes the necessity of prompt standardization of everything essential to convenient exchange of rolling stock.

The communication from Mr. A. H. Babcock is interesting, but has no particular bearing on the general railway problem under consideration. He objects to our expressed opinion that alternating-current equipment is the only class of equipment deserving serious consideration in connection with the general problem of heavy traction. He has found an alternating-current installation comprising three passenger cars and two work cars weighing about 40 tons each. These cars are operated by 25-cycle single-phase current obtained from a 60-cycle source through the interposition of a motor-generator set. The energy is metered and paid for on the three-phase side of this set. The conditions of service are in no way defined, but the limited equipment suggests a very low load-factor and consequently very low efficiency of conversion from 60 cycles to 25 cycles.

Mr. Babcock asserts that if the 1200-volt direct-current system were used the energy per ton-mile would be 30% less. This is easily conceivable, particularly if Mr. Babcock has based his calculations upon the use of synchronous converters in this case as against a motor-generator set as in the other. The case to which he refers is obviously one of ordinary interurban trolley operation, with frequent stops; and in this field many cases of direct-current practice might be adduced in which the energy consumed per ton-mile, owing to special and local conditions, is comparable to that which he has found in this particular instance of alternating current. Obviously, the point which he attempts to make is not one which will materially influence general conclusions in respect to the problem of heavy traction. Mr. Babcock asserts his intention:

> To reserve the right to choose for every specific case the type of apparatus best adapted.

In the interest of the great railway property for which he is retained as electrical engineer, it is to be hoped that he will bestow further consideration upon this very important question of engineering policy. The 1200-volt direct-current system is probably capable of attaining excellent results in a limited field, such as the electrification of a terminal, but generally speaking the system adopted for the electrification of a terminal should be one adapted to future extension to the railway division or even to the trunk line.

The substantial accuracy of the general results of our calculations relative to reduction of operating expense resulting from the substitution of the electric motor for the steam locomotive has not been seriously questioned. Our estimates of the aggregate output and cost of power-house equipment which would be required for the operation of the entire system of the United States rest primarily upon certain stated assumptions as to length of line supply from a given power house, and to this fact some reference has been made in the discussion.

We therefore avail ourselves of the opportunity to supply, in the form of an appendix to our paper, an explanation of methods used in determining power-house output and load-factor, a statement relative to the effect of resistance due to grades, and also a brief statement relative to recuperation.

Clarence Renshaw (by letter): Mr. A. H. Babcock has contributed to the discussion of the Stillwell-Putnam paper by letter. He describes his observations on a visit to a single-phase electric railway. I have been intimately conversant with the operation of this railway through engineering reports from those who have had charge of the installation and initial operation of the apparatus.

Mr. Babcock has neglected to mention a number of facts which materially affect the conclusions which should be drawn from the material which he does give. To overcome certain specific faults in insulation and workmanship, which developed in operation, the motor armatures were rewound. A number of the men whom Mr. Babcock mentions were presumably engaged upon this work, as the normal number which is now employed is very much less.

During the month to which it is presumed Mr. Babcock refers, the total car-mileage of the road was 15,797 miles, including trailers and freight cars. The total motor-car mileage was only 13,009 miles, or approximately 87 miles per car per day. The cars were operated at a schedule of approximately 19.5 miles per hour between terminals, so that the daily mileage of a car represents only about 4.5 hours actual running. Under such circumstances, the load-factor in necessarily very low and the power consumption, on a car-mileage basis, from the 60-cycle circuit, where the power measurements referred to by Mr. Babcock were taken, is necessarily high. This was further accentuated by the fact that, at the time of his visit, polyphase generators which were not well adapted for this service were used for supplying single-phase current. These have since been modified by rewinding them for single-phase operation. Since this modification, one generating set is ordinarily ample for operating the road, whereas two motor-generator sets in parallel were usually required during the month to which Mr. Babcock refers. Consequently, the conversion losses in the sub-station were abnormally high.

Even the figures which are given—153 watt-hours per ton-mile—are not unusual when the load-factor is low. I have a test giving the actual measurements on a road through synchronous converter sub-stations. Three cars of 28 tons operating on this road required 202 watt-hours per ton-mile during the month of January, 1906. This illustrates the high power requirements per ton-mile when there are but few cars and the load-factor is low. A comparison of these two examples shows the marked advantage of single-phase operation under such conditions.

It may be noted that the company operating the road to which Mr. Babcock refers has given a favorable judgment on the operation of the road, as indicated by considerable extension and an increase of more than 100 per cent. in their car equipment.