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THE COST OF ELECTRICALLY-PROPELLED SUBURBAN TRAINS

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51 Electrical propulsion permits of increased speed and capacity, relieves congestion, and increases revenue, for suburban passenger traffic, and permits of the retention of steam-locomotive methods for long-distance traffic.

52 Different systems of electrical propulsion of suburban trains vary greatly as regards the capital outlay per train and also as regards the consumption of electricity per train-mile; consequently in any project for electrical working, it is necessary, not only to compare electrical with steam locomotive methods, but also to compare alternative electrical methods.

53 Preliminary cost estimations are facilitated by assuming that the railway purchases its electricity from electricity-supply companies who themselves own all works up to the distributing system and who supply the electricity in the form in which it is consumed by the train.

54 The chief items of cost, which are different from those entailed by steam-locomotive methods and which are different with different electrical systems, are:

a The cost of the electricity.

b The annual charges for the rolling stock.

c The cost of the distributing system (overhead trolley line or conductor rails and the feeders) between the points where the electricity-supply company delivers the electricity, and the trains.

For the purposes of the paper the assumption is made, with reservations, that item *c* is independent of the particular electrical system

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employed, and the estimates are narrowed down to items *a* and *b*, which, for suburban passenger trains, usually absorb some 35 to 40 per cent of the gross receipts.

55 The two electrical systems subjected to comparison are the systems employing series-wound, continuous-electricity train equipments, termed the continuous system, and the single-phase system. Continuous equipment provides, per ton of equipment, 11 h.p. at the axles, averaged over the journey, as against 6 h.p. per ton in the case of single-phase equipment. In both cases the cost is some £125 per ton of electrical equipment. For a service where trains pass in each direction at intervals of some 12 to 15 minutes, representative figures for the cost of the electricity as delivered to the railway company in the required form, that is, from the sub-stations are: 0.87*d*, per kw-hr. for continuous electricity and 0.70*d*. per kw-hr. for single phase-electricity.

56 Taking into account that the total consumption, after allowing for non-remunerative train movements and for unavoidable departures from the regular time-table, is some 30 per cent greater than the consumption per recorded train-mile, the cost of electricity per recorded train-mile is, for 180-ft. trains, shown to amount, for single-phase trains, to from 10*d*. to 15*d*. per train-mile, and for continuous trains, to from 10*d*. to 13*d*. per train-mile. The lower values are for a 22-mi. per hr. 1-stop per 0.88-mi. service, that is, for a comparatively moderate service; and the higher values are for a 30-mi. per hr. 1-stop per 1.32-mi. service, that is, for a decidedly severe service.

57 The annual charges for the rolling stock for these two services amount to from 8.6*d*. to 10.5*d*. per train-mile for the single-phase trains and to some 6*d*. per train-mile for the continuous trains.

58 The cost of the electricity plus the annual charges for the rolling stock, that is, the sum of the above two items, is, in the case of single-phase trains, some 3*d*. higher per train-mile for the moderate service and some 6*d*. higher for the severe service, than the corresponding costs for continuous trains.

59 Fixing ideas by assuming the gross receipts in these cases to be 50*d*. per train-mile, the single-phase system, compared with the continuous system, absorbs, for the two items in which the selection of the particular electrical system affects the question most greatly, 6 per cent more of the gross receipts in the case of the moderate service and 12 per cent more of the gross receipts in the case of the severe service.

60 The estimates worked out in the paper show that, for suburban passenger traffic, the continuous system has very decided commercial advantages over the single-phase system, and these advantages are greater the more severe the service, that is, the greater the schedule speed and the shorter the distance between stops. This is the precise class of work where electrical methods afford to railways commercial advantages which are unattainable by steam locomotive methods. For services where there are many miles between successive stops and where a considerable time elapses between the passage of successive trains, the use of steam locomotives permits of commercial advantages which are unattainable with any electrical systems comprising the feature of transmitting the energy to the train.

61 *Preliminary Considerations.* The commercial aspects of applying electricity to the propulsion of suburban trains involve many factors and the thorough investigation of any one of these factors requires careful study. In the present paper the author's aim is to focus attention chiefly on the rolling stock, but it must not be inferred that he implies that the other factors affecting the total cost are of minor importance. It is absolutely insufficient to approach the subject of railway electrification from the standpoint that it resolves itself into a mere question of contrasting electric propulsion with steam locomotive propulsion. Were it not for conditions relating to the large amount of capital already invested in steam railways, it is certain that the merits of electrical methods, would, so far as concerns suburban passenger traffic, lead to their general adoption. But the great cities of the world are already very liberally supplied with steam railways which, in addition to much other important traffic, at present handle the suburban passenger traffic for which electrical methods have, on many occasions, been demonstrated to be especially appropriate.

62 Let us however, conjure up the hypothetical case that London is served by all but one of the older of the several great railways now entering it, and which are all of proven necessity, and that the project is mooted of adding this one urgently needed railway. Under these circumstances the author doubts if there would now be found more than a small minority of railway engineers who, in the face of the demonstrated successes of electrical methods of propulsion, would advocate that the suburban passenger service of this new railway should be handled by steam locomotives. The new terminus would probably be designed and equipped so that the suburban traffic would consist exclusively of electrically-propelled trains. It

is equally probable that beyond some 25 to 30 miles from London the through trains would be drawn by steam locomotives. The through-goods traffic would also be operated by steam locomotives. As to whether the long-distance trains should leave the terminus behind steam or electric locomotives is less apparent, and is, furthermore, a matter of secondary importance, since the presence of a certain number of non-stopping steam trains is entirely consistent with the maintenance of an effective service of electrically-propelled suburban passenger trains. Consequently it would not require any drastic alteration of methods gradually to tend more toward steam or more toward electricity for propelling the through trains when traversing the tracks within the 30-mi. radius. This hypothetical case has simply been cited in order to emphasize more forcibly the generally admitted fact that it is no longer a question of whether, in electricity, there has arrived a better agent than the steam locomotive for the handling of suburban traffic. On the contrary, the exclusive though often amply sufficient reason for delay in replacing steam-locomotive methods by electric propulsion, is, so far as concerns the suburban passenger traffic, nearly always related to the large capital expenditure involved in effecting the change. For not applying electrical methods to other classes of railway traffic there is, so far as relates to Great Britain, the best of all reasons, namely, that steam is, at present, in almost all instances, more economical. The presence of frequent tunnels may afford the chief reason for adopting electricity on a given section, owing to the elimination of smoke and steam. But if it is proposed to employ a bare 6000-volt overhead conductor for supplying the trains, the presence of tunnels of small dimensions may afford the most cogent reason for adhering to the steam locomotive. Heavy grades are much more readily negotiated by electrically-propelled trains, and consequently, for mountain lines, there is an additional incentive for substituting electrical propulsion for steam-locomotive methods. In countries where coal is scarce and water power abundant, as, for instance, in Sweden, Italy, and Switzerland, the general electrification of the railways may be a thoroughly sound proposition, but the distinction between the conditions in Britain and in the countries cited is obvious.

63 In view of the circumstances, the question of the relative cost of various electrical systems of operating suburban lines becomes one of great importance. Although it would be premature to deny the claims of certain further systems of electrical propulsion, the two

systems which are, at the present time, chiefly commanding attention, are the systems employing on the trains continuous-electricity motors and single-phase motors respectively. With a view to concentration, only these two systems will be taken into account.

64 The conventional methods which are employed in analyzing the expenses of operating steam railways involve, when applied to estimates for the electrical operation of railways, a considerable degree of obscurity and lead to misunderstandings. The obscurity is often intensified by any attempt to adapt these methods, by slight modifications, to the new conditions attending electrical operation. For the particular investigation which constitutes the object of this paper, it will conduce to clearness to break away completely from these conventional methods of analyzing costs. This is the more justified since the paper deals with broad comparisons, leading to broad generalizations. Were it a question of final and detailed estimates the method employed in this paper would obviously be inappropriate.

65 A railway is an undertaking of such magnitude that, with the extensive adoption of electricity for propulsion, it would often be in the interests of economy for the railway to provide and operate its own electricity-supply stations, and thus save the profits which would be included in the prices at which electricity-supply companies would be prepared to sell the electricity. Nevertheless it is electricity-supply companies, and not the railways, which are at present in a position to supply a railway's requirements to best advantage, and in view of the circumstance that any single railway almost always traverses districts served by many different electricity-supply companies, it is highly probable that for some long time to come, at any rate, a railway would, in many cases, be best serving its own interests by purchasing its electricity from electricity-supply companies and municipal electricity-supply undertakings. It is by no means necessary for the author to investigate this question further, but merely to state that in this investigation, he will assume that the railway not only purchases its electricity from independent undertakings, but that it looks to these independent undertakings to provide all transmission lines from the points where the electricity is generated, and also to provide all the sub-stations, thus delivering the electricity at the required points on the railway company's premises in the form in which it is collected by the trolley-bows or rail-shoes carried by the train. The sub-stations are thus the property of the electricity-supply company. The railway is, however, the proprietor of all the cables and structures intermediary between the sub-stations and the

trains. The railway, in that it owns the property on which its tracks are laid, possesses a great advantage over electricity-supply companies since it can construct its transmission line, whether overhead or underground, without conforming to so many sometimes obstructive regulations, and without payment for way-leaves. By coöperation in extending these advantages to the electricity-supply companies from whom it purchases the electricity, an appreciably lower price should be obtained. These structures may consist in an overhead trolley system, or in conductor-rails, together with in either case, the necessary feeders. When the single-phase system is employed, the sub-stations may contain stationary transformers or they may consist simply of buildings provided with high-pressure switch gear for controlling the inter-connections of the various sections of the line. When the trains are equipped with motors operated by continuous electricity, the sub-stations will be more numerous, and they will be provided chiefly for the purpose of housing motor-generator sets transforming the high-pressure polyphase electricity received from the electricity-supply station, into the relatively low-pressure continuous electricity required at the train. The price charged by the independent electricity-supply undertakings will be for the electricity in the form in which it is delivered from the sub-stations, and owing to the greater cost and lower efficiency of the sub-stations when supplying continuous-electricity, the railway will be obliged to pay a higher price for a given quantity of electricity when it is in the continuous form than when it is in the single-phase form. Prices arrived at by experience on a large scale are now quite well agreed upon for electricity in these two forms. While these prices vary greatly according to the price of fuel and various factors of like nature, and while they also vary greatly with the nature of the load, they can nevertheless be estimated with certainty in any particular case. By allocating to the electricity-supply company the burden of providing the transmission system up to the sub-stations, and also the sub-stations, legitimate simplifications are introduced into the calculations, since there are in Great Britain many electricity-supply companies who are prepared to promptly quote prices for electricity as delivered at the outgoing cables from such sub-stations. For given conditions as regards load factor and price of coal and water, the market price of electricity has for some time been quite a definite quantity.

66 Thus, so far as the outlay for electrical apparatus and equipment is concerned, this method of comparison leads us to the definite proposition of estimating the cost of the rolling stock and the cost

of the structures along the line, intermediary between the sub-stations and the trains. While the cost of these structures has, up to the present, been higher with the single-phase than with the continuous system the author does not propose in this paper to discuss these differences, but he will, on the contrary, assume that the outlay for this portion of the work is the same for both systems. As to the costs of the trains, estimates for each system will be made, since in this respect the two systems differ greatly from one another.

67 To fix ideas, the author will confine his comparisons chiefly to trains consisting of three double-bogie coaches. It is well known that, under reasonably favorable conditions, such trains usually yield gross receipts of some 40*d.* to 60*d.* per train-mile. The cost of the electricity required for the propulsion of the trains, together with reasonable estimates for the capital charges for the trains including the outlay for their depreciation, repairs and renewals, make up an aggregate per train-mile which is usually of the order of from 35 to 40 per cent of the amount of the gross receipts. Into the disposition of the remainder of the gross receipts it is not proposed to enter, since, taking the electrical structures along the line,[1] that is, the equipment intermediary between the sub-stations and the trains, as representing the same outlay, irrespective of the particular system of electric traction adopted, the disposition of this remainder will be substantially the same, whichever system is employed, and hence does not materially affect the results in a comparison of systems. It is to the application of that portion of the gross receipts, roughly 35 to 40 per cent or thereabouts, the precise amount of which is seriously affected by the selection of the service and of the system of electrification, that the author will direct his investigations. It may be said that he is guilty of comparing alternative systems of electrical operation to the disadvantage of the interests of electrical operation in general, but he does not admit this to be the case. On the contrary, a correct interpretation of his results will show that his object is to consecrate each system to its appropriate purpose, and to admit fully that for long-

[1] This is the only electrical item which is not included in the comparisons, and since it will introduce no serious error to take this item as independent of the particular electrical system adopted, the author considers it preferable, in this investigation, to group it with the various non-electrical items, including net profits, which make up the remaining 60 to 65 per cent of the gross receipts, and which, directly, are independent of the precise electrical system adopted, although indirectly they may be appreciably affected. For instance, the design and weight of the train affects the permanent-way outlays.

distance through trains, steam-locomotive methods are superior to any electrical methods as at present developed. For high speeds with frequent stops, while both the single-phase system and the continuous system have long been recognized to be adequate as regards their engineering features, the former entails, as he will endeavor to show in this paper, distinctly greater outlay and distinctly less net earnings. He will also endeavor to show that with decreasing speed for a given distance between stops, or with increasing distance between stops for a given speed, the disabilities of the single-phase system become less acute. The determination of the point beyond which the uses of the single-phase system will conduce to greater net earnings than can be obtained by the system employing continuous electricity at the trains, is, however, not within the range comprised by the subject assigned to the Joint Meeting for discussion, namely The Electrification of Suburban Railways, and hence cannot appropriately be dealt with in this paper. Quite aside from any question of the relative merits of alternative systems, the author would be pleased if the results which he has deduced as regards the cost of the rolling stock and of the electricity consumed in its propulsion, should be found useful in dealing with electric railway investigations.

68 The severity of a train service is a function of the schedule speed and of the distance between stops. For a very severe service, many of the train axles are often driven by motors, while for more moderate services it suffices to concentrate the driving power upon but a few of the axles. In eliminating the locomotive and placing the motors under the passenger coaches, the space available for the motors is rather restricted, and the plan of distributing several relatively small motors on several axles is more often a consequence of this space limitation than of any regard for obtaining greater tractive effort by the greater total weight on the driven axles. Although this latter object is always kept in view, it may be said that even the high accelerations employed on electric railways rarely require so great a subdivision of the driving power as is, for severe services, usually resorted to, owing to the space limitations.

69 *Analysis of Two 150-ft. Trains.* The author proposes first to analyze the design and performance of two 150-ft. trains designed for about the same average output, and similar as regards the capacity and distribution of the electrical equipment. In the two 150-ft. trains which have been selected for this analysis, only two motors are employed, and these drive two of the four axles of a motor coach. Each

of these 150-ft. trains comprises three 50-ft.[1] coaches, of which one is a motor coach and the other two are trailer coaches. Thus out of the twelve axles, only two are driven. The first of these two trains is a type designated *A*, which is employed on the Picadilly-Tube Railway in London and weighs 61 tons; the second is a type designated *C*, which is employed on the Heysham, Morecambe and Lancaster Branch of the Midland Railway and weighs 77 tons. The service for which the 61-ton Piccadilly-Tube train is employed requires a schedule speed of 16.4 mi. per hr, and the runs are of an average distance of 0.45 mi. between stations. The 77-ton Heysham train has a schedule speed of some 31 mi. per hr., and there is an average distance of 4 miles between stations. It might appear at first sight that these two services are not comparable, but brief calculations are given below, showing that the average output to the axles is just about the same in the two cases. Furthermore, the average efficiencies of the two electrical equipments do not differ by more than 5 per cent at the outside. This is also the case as regards the efficiencies in the two cases of 180-ft. trains, examined in a later section of this paper, and with a view to avoiding a discussion of so unessential a matter as a few per cent difference in efficiency, the author has, throughout his comparisons, employed the mean value of 70 per cent. His examinations indicate that in no one of the four cases (that is, the two 150-ft. trains and the two 180-ft. trains) is the average efficiency of the electrical equipment on the train for the services for which the trains are employed greater than 72 per cent or less than 68 per cent; consequently the employment throughout of the value of 70 per cent is amply exact and is in the interests of simplicity. The two particular instances of two-motor 150-ft. trains have been taken because precise data of their design and performance are available, and because, while they are equipped for about the same average output, one train carries continuous-electricity equipment and the other carries single-phase equipment. For the 61-ton Piccadilly train, the output of the equipment, averaged over the entire time, including stops, is 87 h.p.; for the 77-ton Heysham train the corresponding figure is 90 h.p. The total weight of the electrical equipment in the two cases is 8.0 tons and 14.9 tons respectively. This estimate of 8.0 tons is somewhat in excess of the weight usually assigned to the equipment of the Pic-

[1] Throughout this paper, it has been convenient to take as the length of the train the length of each coach multiplied by the number of coaches, that is the length corresponding to buffers and couplings has not been included.

cadilly-Tube trains. The figure usually given is 7.3 tons, but the author prefers to take 8.0 tons since the weight of auxiliary equipment tends to gradually increase in successive installations. This is because with the development of electrical methods, refinements are introduced which were not deemed necessary in the earlier work. This estimate of 8.0 tons is ample to cover air-compressors and governors, all cables, slate switch-panels, collecting shoes, and shoe-beams for both trucks of the motor-coach, steel-tubing bolts, cleats, etc. The estimate of 14.9 tons is for the Siemens Company's equipment as installed on the Heysham train. In each case the service is that for which the equipment was selected. In both cases, the capacity of the motors is probably sufficiently liberal to permit that the motor-coach, with its equipment, may haul three trailers instead of two, for considerable periods. Indeed four-coach Piccadilly trains have been found by tests to be well within the capacity of the two motors of a single motor-coach. But nevertheless the use of two trailers per motor-coach is, both for the Piccadilly and the Heysham lines, the normal case. In each case the ultimate temperature rise in regular service is of moderate amount. Whereas, in the case of the Piccadilly-Tube train, forced draft is not employed, the motors on the Heysham train are only maintained at a sufficiently low temperature by employing forced draft. Consequently the lightness of the continuous-electricity equipment, as compared with the single-phase equipment of the same average output, is the more marked. It should be further borne in mind that, in endeavoring to keep down their weight, single-phase motors are designed with a higher speed, in revolutions per minute, than has been considered good practice with continuous motors, and the required speed at the train axles is in single-phase trains obtained by the interposition of undesirably high gear ratios. Thus we have: Average output in service per tons of electrical equipment

$$\frac{8.7}{8.0} = 10.9 \text{ h.p. for the Piccadilly train}$$

and

$$\frac{9.0}{14.9} = 6.04 \text{ h.p. for the Heysham train}$$

The calculations are set forth in parallel columns in Table 3. In these calculations, as also in those in Table 4, the values for the energy consumption per ton-mile correspond with the representative values given in Table 9, and represent the consumptions under the conditions of test runs. The question of the additional consumption to allow for the conditions of routine service, is introduced in a later section of this paper.

70 *Analysis of Two 180-ft. Trains.* Having now examined two 150-ft. trains composed of one motor coach and two trailers, let us turn our attention to two trains for more severe services. The two trains which the author has selected for his purpose are each 180 ft. in length and are each composed of two motor coaches and one trailer coach.

TABLE 3 AVERAGE OUTPUT IN SERVICE PER TON OF ELECTRIC EQUIPMENT ON PICCADILLY AND HEYSHAM TRAINS

	Piccadilly Train	Heysham Train
Number of motor-coaches	1	1
Number of trailer-coaches	2	2
Total number of coaches in the train	3	3
Number of motors	2	2
Total number of axles in the train	12	12
Number of axles driven by motors	2	2
Length of train, ft.	150	150
Weight of train, tons	61	77
Schedule speed, (*a*) mi. per hr	16.4	31.0
Distance between stops, mi	0.45	4
Energy consumption per ton-mile, watt-hr	93	40
Energy per train-mile, (*b*) kw-hr	5.67	3.08
Average input per train (= $a \times b$), kw	93.0	95.6
Average output from motors to axles taking average efficiency of electrical equipment as 70 percent, h.p	87	90
Weight of electrical equipment, tons	8.0	14.9
Average output per ton of electrical equipment, h.p	10.9	6.04
Ratio of these two average outputs per ton of electrical equipment	$\frac{10.9}{6.04} = 1.81$	

[1] The electrically-equipped rolling stock on the Heysham line comprises three such trains. Their aggregate mileage for the year ending June 30, 1909, was only 86,000 miles, or an average of only 79 mi. per train per day. At 31 mi. per hr. this works out at only 2½ hr. per train per day. In the analysis, however, the author is crediting the Heysham trains with having an equipment adequate to work to a schedule speed of 31 mi. per hr. for many consective hours. The Piccadilly-Tube trains do this, day after day, a single train often maintaining its schedule speed for 18 consecutive hours and covering in that time 300 miles.

Each coach is 60 ft. in length. Each motor-coach is equipped with four motors, making up a total of eight motors per train. Thus eight of the twelve axles of the trains are driven by motors, whereas in the two former trains only two out of the twelve axles were driven. The first of these two 180-ft. trains is of a type which may be designated as *B*, and which is employed on the Southport line, and the second which may be designated as *D*, and which is one of the trains now operating on the South London Elevated Railway. The trains are thus somewhat longer and are much heavier than those which we have examined before. The weights of these two 180-ft. trains are respectively 118 tons and 138 tons. The Southport train runs at a schedule speed of 30 mi. per hr. and the average distance between stations is 1.32 mi. The South London elevated train, which will be designated the S.L.E. train, runs at a schedule speed of 22 mi. per hr., and the average distance between stations is 0.88 mi. The striking similarity of these trains as regards their length (180 ft.), their seating capacity,

TABLE 4 AVERAGE OUTPUT IN SERVICE PER TON OF ELECTRIC EQUIPMENT ON SOUTHPORT AND S. L. E. TRAINS

	Southport Train	South London Elevated Train
Number of motor-coaches	2	2
Number of trailer-coaches	1	1
Total number of coaches in the train	3	3
Number of motors	8	8
Total number of axles in the train	12	12
Number of axles driven by motors	8	8
Length of train, ft	180	180
Weight of train, tons	118	138
Schedule speed (a), mi. per hr	30	22
Distance between stops, mi	1.32	0.88
Energy consumption per ton-mile, watt-hr	96	79
Energy consumption per train-mile (b), kw-hr	11.3	10.9
Average input per train ($= a \times b$), kw	340	240
Average output from motors to axles (taking average efficiency of electrical equipment at 70 per cent), h.p.	319	225
Weight of electrical equipment, tons	30	44
Average output per ton of electrical equipment, h.p.	10.6	5.12
Ratio of these two average outputs per ton of electrical equipment	$\frac{10.6}{5.12} = 2.07$	

and the proportion of motor and trailer-coaches, has led to the establishment of comparisons between them. But these comparisons have usually been of an utterly superficial nature. It has been said that since in the case of the Southport train the stops are less frequent and the speed is higher, the severity of the service is substantially the same as in the case of the S.L.E. train, and it has been assumed, though altogether incorrectly, that the more frequent stops in the case of the S.L.E. train offset the greater speed in the case of the Southport train. The author has, however, pointed out on various occasions that this is not the case. On the contrary, the power which is required at the axles in the case of the Southport 118-ton train is 42 per cent greater than the power which is required at the axles for the S.L.E.

138-ton train, notwithstanding the 18 per cent greater weight of the latter train, and the power required at the axles, per ton of total train weight, is no less than 65 per cent greater for the Southport service than for the S.L.E. service. Some engineers are doubtless well aware of the erroneous character of the assertions which have been made in this matter, but it is probable that other engineers have unguardedly accepted the assertions, and have concluded that for practical purposes the two services may be regarded as substantially equal in severity.

71 The service performed by the Southport 118-ton train requires of the electrical equipment an output to the axles, averaged over the entire run, of 319 h.p., whereas the relatively much less severe service of the S.L.E. 138-ton train requires an output to the axles of only 225 h.p. The weights of the electrical equipments in the two cases are, however, 30 and 44 tons respectively. The average horsepower output to the axles per ton of electrical equipment, works out respectively at 10.6 h.p. for the Southport train, and 5.12 h.p. for the S.L.E. train. As a matter of fact, the Southport trains operating to the schedule in question, while still comprising two motor coaches, each equipped with four motors, very frequently have two trailer coaches, and it is consequently very conservative to take the three-coach train as representative of the capacity of the electrical equipment of two motor coaches. In the Board of Trade returns for 1908, the electrical train service on the Southport line is given as 1,490,000 train-miles and 5,120,000 car-miles. The average train thus comprises 3.4 coaches, which more than justifies the author's standpoint. Possibly also the S.L.E. equipment has a similar margin of capacity. Whether or no this be the case, it is as well to base the comparisons on the three-coach trains in each case, although this is decidedly less than the normal train for the Southport line, whereas it is the standard type of train operated on the S.L.E. Railway. In Table 4 these calculations are set forth in parallel columns.

72 It will be observed that the average output per ton of electrical equipment varies greatly in the four cases which we have examined, and questions naturally arise as to the cause of these great variations. It might be suggested that the variations are attributable to diverging views as to correct methods of design. As it happens, however, the equipments were supplied by four different manufacturers who are among the half-dozen firms who probably have the greatest experience in the manufacture of electric railway equipments. Denoting the four examples as A, B, C and D, we arrive at Table 5.

73 Engineers familiar with the relative standing of the leading manufacturers of electric railway apparatus, are well aware that each of these four firms have resources of such magnitude that they are all on a substantially equal footing as regards ability to produce the best, lightest and cheapest apparatus for the purpose in view. Consequently we must seek some other explanation for the striking difference in the results set forth in Table 5. The two first results are within

TABLE 5 COMPARISON OF AVERAGE OUTPUT

Example	Average Output per Ton of Electrical Equipment, h.p.	Railway	Manufacturer
A	10.9	Piccadilly	B. T. H. Co.
B	10.6	Southport	Dick, Kerr & Co.
C	6.04	Heysham	Siemens
D	5.12	S. L. E.	A. E. G.

3 per cent of each other and the last two results are within 18 per cent of each other. That the S.L.E. equipment works out at only 5.12 h.p. per ton while the Heysham equipment comes to 6.04 h.p per ton, is satisfactorily explained by the circumstance to which allusion has already been made in the footnote to Table 3, to the effect that the Heysham train only averages (over the whole year) some 2½ hr. of service per day whereas the S.L.E. trains will doubtless average (over the 365 days in the year) at least twice this number of hours of service per day. It is stated that for the S.L.E. line, "the mileage of each train service varies between 250 and 500 miles per day." The mean of the first two results is 10.8 h.p. per ton, and the mean of the last two results is 5.6 h.p. per ton. These two values have the ratio 1.93: 1.00. The reason for this difference in weight of about 2 to 1 is that in the first two cases, that is, the Piccadilly-Tube 61-ton train and the Southport 118-ton train, the equipments are designed for, and operated with, continuous electricity, whereas the last two cases, the Heysham 77-ton train and the S.L.E. 138-ton train, have equipments designed for, and operated with, single-phase electricity.

74 As rough, but representative values, we may take it that for a train equipped with continuous apparatus, the electrical equipment may, in actual service, and for approved overload and heating limits, be loaded up to an average output of 11 h.p. per ton-weight of the equipment, whereas single-phase equipments can only be worked up

to an average output of 6 h.p. per ton.[1] It has been asserted that notwithstanding that the single-phase equipment for a train required to perform a given service, weighs twice as much per horsepower as the corresponding continuous equipment, this does not seriously affect the total train weight, since the weight of the electrical equipment constitutes (it is alleged) only a small part of the total weight of the train. Let us investigate this assertion. In Table 5 the four trains have been designated as *A*, *B*, *C* and *D*. In Table 6 are given the total train weights, the weight of the electrical equipment, and the percentage which the weight of the electrical equipment constitutes of the total train weight.

TABLE 6 TOTAL TRAIN WEIGHTS

System	Designation of Train	Railway	Length of Train, Feet	Total Train Weight, Tons	Weight of Electrical Equipment, Tons	Percentage which Weight of Electrical Equipment Constitutes of the Total Weight of the Train, Per Cent
Continuous...	*A*	Piccadilly	150	61	8.0	13.1
Continuous...	*B*	Southport	180	118	30	25.4
Single-phase.	*C*	Heysham	150	77	14.9	19.3
Single-phase.	*D*	S. L. E.	180	138	44	32.0

75 Comparing the 180-ft. trains, that is, trains *B* and *D*, we have seen that the Southport service is much the more severe, yet the electrical equipment of the Southport train only amounts to 25.4 per cent of the total weight, as against 32 per cent of the total weight for the much less severe S.L.E. service. It should be of interest to ascertain how a train of the *D* type would require to be modified in order to be suitable to perform the *B* service. This and subsequent calculations will be simplified by first working out, for all the trains, the average horsepower per ton-weight of train required for the respective services. This is done in Table 7.

[1] It should be noted that the author is favoring the single-phase system very decidedly in crediting it with an average output of 6 hp. per ton, for this value is only attained in the case of the Heysham trains, which only average 2½ hr. in service per day, whereas the S.L.E. trains, which do an average of, say, 5 hr. per day, yield an average output per day of only 5.12 h.p. per ton-weight of electrical equipment.

76 The values in the lowest horizontal line of Table 7 are the real criteria of the severity of the service, and we see that the Southport service requires $\left(\text{since } \frac{2.70}{1.63} = 1.65\right)$ 65 per cent more average power per ton-weight of train than is required for the S.L.E. service. The values in the lower line of Table 7 are, since the efficiency is the same, independent of whether single-phase or continuous apparatus is employed. For the Southport service, there must be provided 2.7 h.p. per ton-weight of train. Since we have seen that, with single phase equipment, we obtain 6 h.p. per ton of equipment, we shall require $\frac{2.7}{6.0} = 0.45$ ton of electrical equipment for every ton of total weight of train. Thus 45 per cent of the weight of the train will consist of electrical equipment.

TABLE 7 AVERAGE H.P. PER TON WEIGHT OF TRAIN

System	Continuous		Single-phase	
Designation of train	*A*	*B*	*C*	*D*
Road	Piccadilly	Southport	Heysham	S. L. E.
Length of train, ft	150	180	150	180
Weight of train, tons	61	118	77	138
Average output during service, h.p.	87	319	90	225
Average output per ton weight of train, h.p.	1.42	2.70	1.17	1.63

77 The motor coaches on the S.L.E. line weigh 54 tons each. Of this 54 tons weight of one of these motor coaches, only 22 tons, that is, only 41 per cent of the total weight of the motor coach is electrical equipment, and consequently the motor coach which is at present running the S.L.E. service, even with its motors rewound for the required speed, would not have sufficient capacity, leaving the same margin as on the present S.L.E. service (Par. 71), to accomplish the Southport schedule with the same heating of the electrical equipment as in the S.L.E. service, much less could a train composed of two motor coaches and one trailer accomplish this schedule with normal heating and with appropriate overload capacity. In order to work the S.L.E. 180-ft. train to the Southport schedule, its electrical equipment must be considerably increased in weight. Let W equal the total weight of the S.L.E. 180-ft. train, in tons, when reinforced to render it adequate for the Southport service. Then the electrical equipment must weigh 0.45 W. The weight of the S.L.E. 180-ft. train exclusive of

the electrical equipment, is 138 − 44 = 94 tons. Its revised weight when provided with an equipment enabling it to conform to the Southport service, will consequently be

$$W = 0.45 \times W + 94$$

Consequently we have

$$W = 171 \text{ tons}$$

78 The weight of the electrical equipment must thus be

$$171 - 94 = 77 \text{ tons}$$

and the electrical equipment will be capable of delivering an average output of 6 × 77 = 462 h.p. Thus the equipment of the S.L.E. train must be increased, as regards its average output, from the 225 h.p. which sufficed for the S.L.E. service, up to the 462 h.p. necessary in order that it may accomplish the Southport service. This is an increase of 105 per cent. The revised S.L.E. train requires to have 462 h.p. average capacity as against the Southport train's 319 h.p. average capacity, an excess of 45 per cent. This further 45 per cent serves no more useful purpose than to carry over the route the increased weight of expensive electrical equipment made necessary by the use of the single-phase system. The revised S.L.E. train weighs 171 tons as against the Southport train's weight of only 118 tons. Thus the result is, that while both trains have the same length of 180 feet, the S.L.E. train, when altered to be adequate to perform the Southport service, weighs 45 per cent more than the Southport train. Moreover, the revised three-coach single-phase train for the Southport service would have to consist of three motor-coaches, in place of the two motor-coaches and one trailer which sufficed to carry the necessary single-phase equipment to perform the S.L.E. service.

79 Let us next reverse the above process and adapt the Southport train to the S.L.E. service of 22 mi. per hr. and one stop every 0.88 mile. This service requires, as seen from Table 7, only 1.63 h.p. per ton of total weight of train. The weight of 1.63 h.p. of continuous equipment is only $\frac{1.63}{11} = 0.148$ ton. Consequently out of each ton of total train weight, only 14.8 per cent will consist of electrical equipment as against the 32 per cent seen from Table 6 to be required when the S.L.E. service is provided by a train equipped with single-phase apparatus. Let us again represent by W the total train weight in tons. Then the weight of the electrical equipment in tons amounts to $0.148 \times W$. The weight of the Southport train, exclusive of the electrical equipment, is 118 − 30 = 88 tons. Consequently $W = 0.148 \times W + 88 = 103$ tons. The weight of the electrical equipment of the revised

Southport train, that is, of the continuous train capable of working to the relatively moderate S.L.E. service, is only $0.148 \times 103 = 15.3$ tons, or only 51 per cent of the 30 tons weight of the electrical equipment required for the Southport train performing the severe Southport service. Obviously then, were we to operate a 180-ft. train to the S.L.E. schedule, employing continuous equipment instead of single-phase equipment, we should not require two motor coaches, but we should make up our three-coach train of one motor coach and two trailers. The continuous equipment thus weighs only 15.3 tons, or only 34.8 per cent of the 44 tons required for the single-phase train of equal length. It is interesting to note that this continuous-electricity train operating on the S.L.E. service is only required to give an average output of $15.3 \times 11 = 168.5$ h.p. which amounts to only $\left(\frac{168.5}{225} =\right)$ 75 per cent of the average output required of the motors on the single-phase 138-ton S.L.E. train.

80 *Cost Estimations.* A rough but thoroughly representative figure for the cost of continuous equipment for railways is £125 per ton. Single-phase equipment at present costs decidedly more, but for the purposes of this investigation the author will take the cost of the electrical equipment, irrespective of whether it is continuous or single-phase, at £125 per ton. Thus for the four trains under consideration, the costs for the electrical equipment work out as in Table 8.

TABLE 8 COSTS FOR ELECTRICAL EQUIPMENT

Electrical Equipment of One Train		Weight, Tons	Cost per Ton, £	Total Cost, £
Continuous train for............	Southport service.	30	125	3750
Continuous train for...........	S.L.E. service.....	15.3	125	1910
Single-phase train for...........	Southport service.	77	125	9630
Single-phase train for...........	S.L.E. service.....	44	125	5500

As to the cost of the remainder of the train, the estimates will be based on the following data:

81 *Bogie Trucks.* The weight of each motor-truck, including truck-frames, wheels, axles, brake-rigging, etc., will be taken at 6.5 tons, the weight of each trailing truck at 5.5 tons. In both cases, the cost of the complete trucks will be taken at £22 per ton. The weight of all the trucks is:

For a train comprising 3 motor coaches and no trailer (12 driven axles)..39 tons
For a train comprising 2 motor coaches and 1 trailer (8 driven axles)...37 tons
For a train comprising 1 motor coach and 2 trailers (4 driven axles)......35 tons

The cost of the trucks for these three trains is:

Three motor-coaches and no trailer....................................£860
Two motor-coaches and 1 trailer....................................£815
One motor coach and 2 trailers...£770

The weight of the three coach bodies, complete with underframes, brake-cylinders, upholstering, etc., is:

Continuous train for Southport service.........118 − 30.0 − 37 = 51.0 tons
Continuous train for S.L.E. service.............103 − 15.3 − 35 = 52.7 tons
Single-phase trains for Southport service........171 − 77.0 − 39 = 55.0 tons
Single-phase train for S.L.E. service.............138 − 44.0 − 37 = 57.0 tons

82 For an absolutely consistent comparison, these four cases should have all worked out at the same value as regards the aggregate weight of the three coach bodies. They are, however, so nearly identical, varying only 6 per cent from the mean value, that their mean value may be taken as representative for the weight of the coach bodies of a 180-ft. train for this type of service. The mean value is 54 tons, or $\frac{54}{3} = 18$ tons for each coach body. These coach bodies, complete, may be taken as costing £80 per ton. Thus for all four trains the aggregate cost of the three coach bodies, weighing 54 tons, will be $80 \times 54 =$ £4320.

83 The costs of assembling, and all further costs, will be taken at £5 per ton of train. These further costs are, consequently, for the four trains:

Continuous train for Southport service.......................5 × 118 = £590
Continuous train for S.L.E. service..........................5 × 103 = £515
Single-phase train for Southport service.....................5 × 171 = £855
Single-phase train for S.L.E. service.........................5 × 138 = £690

84 The total costs of the four trains are made up as shown in Table 9.

85 Since these trains have a seating capacity of, roughly, one seat per foot, the two lower horizontal lines in Table 9 also give a fair representation of the relative costs and weights per seat. We see that for so severe a service as that at Southport, the cost of a single-phase train (since $\frac{87.0}{52.6} = 1.65$) works out to be 65 per cent greater per foot of

length than is the cost of a continuous train. For the much more moderate service of the S.L.E. line, the excess cost of the single-phase train per foot of length is only 51 per cent (since $\frac{63.0}{41.7} = 1.51$), and the percentage continues to fall with every amelioration in the severity of the service.

TABLE 9 TOTAL COSTS OF THE FOUR TRAINS

	Continuous Train		Single-Phase Train	
	For Southport Service, £	For S.L.E. Service, £	For Southport Service, £	For S.L.E. Service, £
Trucks	815	770	860	815
Car bodies	4320	4320	4320	4320
Electrical equipment	3750	1910	9630	5500
Further costs	590	515	855	690
Total cost of train	9475	7515	15,665	11,325
Weight of train, tons	118	103	171	138
Cost per ton	£80.3	£72.7	£91.6	£82.1
Length of train, ft	180	180	180	180
Cost per ft	£52.6	£41.7	£87.0	£63.0
Weight per ft., ton	0.655	0.575	0.95	0.77

86 It is usually preferable to reduce weights and costs to the basis of the weight and cost per foot length of train instead of per seat. Mr. J. R. Chapman, late Chief Engineer of the Underground Electric Railways Company of London, has also advocated the reduction of data to terms of the foot length of train, instead of to terms of per seat, in the following words: "The arrangement of seats in a car has no more to do with electrical working than the color of paint used on the outside. A car will carry the maximum number of passengers if it has no seats at all; it will carry the minimum number if it is fitted with arm-chairs. Somewhere in between these two designs there is a medium which fits the average conditions which the particular railway has to meet, and I think that as cars vary in size, and seating arrangements also vary, the comparison should be made per lineal foot of train, or per square foot of floor devoted to passenger accommodation; probably the latter is the best, as it brings into the calculation the alternative of equipment underneath the car, as on the district, or equipment in a cab, as on the tubes; the latter system reduces passenger accommodation but costs less for maintenance. Otherwise it is very difficult to effect comparisons, for not only have we to take into account the varying composition of trains as regards first and third

class carriages, but there is the further consideration that the policy of railways differs considerably as to the floor space and elbow room which are allotted to each passenger. Since, however, the average value of the seats per foot for representative passenger trains of mixed composition rarely varies much from unity, the values of the weight and cost per foot enable us to readily make mental calculations, as occasion requires, of the corresponding weights and costs per seat. It is preferable, in all cases, to take the weights of the trains themselves, and to leave out of consideration the weights of the passengers. Table 10, giving the number of seats per foot of overall length of train for several typical trains, will be interesting, as bearing upon this point.

TABLE 10 NUMBER OF SEATS PER FT. OF OVERALL LENGTH OF TRAIN

Railway	Composition of Train M = Motor-Coach T = Trailer-Coach	Number of Seats			Length of Train in Ft.	Seats per Ft. of Overall Length
		3rd Class	1st Class	Total		
Southport	(a) $2\,M + 2\,T$	138	132	270	240	1.13
	(b) $2\,M + 2\,T$	218	66	284	240	1.18
Heysham	$1\,M + 2\,T$	....	....	180	150	1.20
Mersey	$1\,M + 1\,T$	64	46	110	120	0.92
North Eastern	$2\,M + 1\,T$	116	70	186	171	1.09

87 *The Cost of the Energy Consumed at the Train.* We have now deduced fairly definite values for the weights and costs of the rolling stock. The component of the total cost represented by the electricity consumed by the train is also fairly definite for a given service. The consumption at the train is for a given service about the same per ton-mile whether the electrical equipment be continuous or single-phase. The values in Table 11 afford a reasonable basis for estimating the consumption at the train per ton-mile of actual performance, when the train is handled by a fairly experienced driver and when it is running strictly to its time table, and over a well built, fairly straight and level permanent way. Although quite practicable variations in the acceleration and braking may easily occasion variations of 10 per cent or more in the energy consumption at the train, nevertheless the values in Table 11 are representative of the customary results obtained under the conditions stated. In the author's opinion the energy consumption per ton-mile is, for frequently-stopping trains, very much less dependent upon the weight and length of the train than

is generally believed. It would be too irrelevant to the present discussion to enter upon the consideration of this point further than to state that the energy-consumption values in Table 11 are consistent for test runs with trains coming within the range of lengths and weights considered in this paper.

88 In the case of passenger trains it is preferable for uniformity's sake to estimate the ton-mileage on the basis of the weight of the empty train. The unrecorded ton-mileage corresponding to the weight of the passengers carried, together with that corresponding to shunting operations and other non-remunerative running, as well as the increased consumption on occasions when the time table is disarranged, will usually bring up the total consumption at the train to a value some 30 per cent greater than the values given in Table 11. This increase is only in small part due to the weight of the passengers since with average loads, the weight of the passengers rarely increases the weight of the train by more than some 5 to 6 per cent. In the following estimates the author will take the consumption of electricity at the train as 1.30 times the values in Table 11. To simplify the investigation he will not go into the question of whether the railway provides its own generating plant or purchases the electricity from a

TABLE 11 ENERGY CONSUMPTION IN WATT-HOURS PER TON-MILE FOR THE VARIOUS VALUES OF THE DISTANCE IN MILES BETWEEN STOPS SET FORTH AT THE HEADS OF THE VERTICAL COLUMNS, AND FOR 20-SEC. STOPS

Schedule Speed in mi. per Hr.	0.5	0.6	0.7	0.8	0.9	1.0	1.25	1.5
15	68	58	50	....	....	....	....	....
16	78	66	56	50	....	....	....	....
17	93	76	63	55	50	....	....	....
18	114	90	73	62	55	48	....	....
19	....	104	83	70	60	53	....	....
20	....	....	94	78	66	58	47	....
22	....	....	....	95	77	67	54	....
24	....	....	....	....	98	83	65	55
26	....	....	....	....	....	100	78	63
28	....	....	....	....	....	....	89	73
30	....	....	....	....	....	....	104	82

supply company; but he will merely assume that the electricity is obtained at a total cost of 0.65*d.* per kw-hr. as delivered to the sub-stations. Owing to the greater loss in transformation at the sub-stations and the greater cost of the sub-stations, in the continuous, as contrasted with the single-phase system, he will take the cost of the electricity as delivered from the sub-stations at 0.70*d.* per kw-hr. for the single-phase system, and at 0.87*d.* per kw-hr. for the continuous system. These amounts cover all outlays, both capital and operating, up to the outgoing cables from the sub-stations. The losses in the transmission system from the sub-stations to the trains are of but small amount in either system. To allow for them he will take the cost of the electricity delivered at the trains as 0.72*d.* per kw-hr. for the single-phase system, and 0.90*d.* per kw-hr. for the continuous system. These last increases in the cost simply allow for the electricity wasted in the process of being conveyed from the sub-stations to the trains, and do not allow for the capital and maintenance charges for the cables and the conductor-rails or overhead structures by means of which the electricity is conveyed from the sub-stations to the trains. The two figures of 0.72*d.* and 0.90*d.* per kw-hr. respectively are thoroughly representative as regards their relative values, though their actual values, while representative, will vary considerably according to many local circumstances.

89 Furthermore these values are only applicable for the conditions of a suburban service of passenger trains where the trains in each direction run, as an average, at intervals of some twelve to fifteen minutes during some sixteen to twenty hours per day. For a less intense-service, the price for continuous electricity will exceed that for single phase electricity by a greater percentage, since the cost of the sub-stations will constitute a larger item, and the all-day efficiency of the sub-stations will be less. If, on the contrary, the trains run at intervals of only some three to six minutes, then also the relative figures of 0.72*d.* and 0.90*d.* at the trains are not applicable; 0.69*d.* for the single-phase system, and 0.83*d* for the continuous system, would then be more appropriate, the latter in this case exceeding the former by only 20 per cent as against 25 per cent in the case of the twelve to fifteen minutes' service. This is because, while the cost of the electricity, as delivered at the trains, in the cases of both systems, decreases with the intensity of traffic, the decrease is a greater amount for the continuous system, owing to the better load-factor at the sub-stations and the consequent considerable reduction in the capital charges and operating expenses of the sub-stations. For his further comparisons, however, the author will take the figures of 0.72*d.* for the single-phase system and 0.90*d* for the continuous system for the cost of electricity per kw-hr. delivered at the trains.

90 With these data, we may now estimate the cost of the electricity consumed by 180-ft. trains operating to the Southport service (as an instance of a severe service) and to the S.L.E. service (as an in-

stance of a much more moderate service). The price actually paid for the electricity for the S.L.E. trains is, at present, decidedly higher than the figures here taken, but the fairly high price in that instance is probably, to some extent, incidental to the experimental nature of the undertaking at this stage. It is well known that in most districts there would, under the conditions already indicated, be reasonable profit in supplying railways with electricity at the prices stated, and hence it is only on the basis of such prices that the comparisons will lead to useful results.

91 To fix ideas, it can be taken that the author's figures relate to a hypothetical road so situated that his prices for electricity are applicable, and have been quoted, and that the engineers of this road are engaged in determining

a Whether to use the continuous or the single-phase system.

b The schedule speed to be provided on various sections of line with various distances between stations.

TABLE 12 DATA FOR COMPARATIVE RESULTS OF FOUR TYPICAL CASES

Designating Number	Length of Train, Ft.	Average Distance Between Stations, Mi.	Schedule Speed, Mi. per Hr.	System
I	180	1 32	30	continuous
II	180	1.32	30	single-phase
III	180	0.88	22	continuous
IV	180	0.88	22	single-phase

92 Prior to making some detailed estimates, the engineers of this railway will first arrive at some general comparative results, as follows

93 Let the comparison relate to four cases, I, II, III and IV. The general particulars of these cases are set forth in Table 12.

94 Out of the 8760 hours in the year, it is rarely practicable, on other than tube railways or railways providing the class of service associated with tube railways, to attain (for suburban passenger trains) to much more than 2000 hours of actual service on the line. Usually the figure is decidedly less than 2000 hours.

95 For a schedule speed of 30 mi. per hr. the profitable mileage per train per annum, on the basis of 2000 hours, works out at 60,000 miles, and for a schedule speed of 22 mi. per hr. it works out at 44,000 miles. Under the conditions of actual service, there will not be so much difference as this, between the annual average mileage per train, for these two schedules. The more the service conforms to the condi-

tions of a tramway service, the more uniform and continuous will be the sequence of trains; consequently, for the 22 mi. per hr. case the author will take the annual average mileage per train at 48,000 miles instead of the above 44,000 miles, and for the 30 mi. per hr. case he will take the annual average mileage at 54,000 miles instead of the above 60,000 miles.

96 The total cost of electricity per annum per train is obtained as shown in Table 13.

TABLE 13 TOTAL COST OF ELECTRICITY PER ANNUM PER TRAIN

Schedule speed, mi. per hr.	30		22	
Distance between stops, mi.	1.32		0.88	
Designating number	I	II	III	IV
System	continuous	single-phase	continuous	single-phase
Weight of train (from Table 9), tons	118	171	103	138
Net consumption of electricity at train in watt-hr. per ton-mile (from Table 11)	96	96	79	79
Net consumption of electricity at train in kw-hr. per train-mile	11.3	16.4	8.2	10.9
Miles per train per annum	54,000	54,000	48,000	48,000
Net consumption per train per annum (kw-hr)	610,000	886,000	394,000	523,000
Gross consumption per train per annum (= 1.30 × net consumption) kw-hr	793,000	1,150,000	512,000	680,000
Cost of electricity delivered at train per kw-hr., *d*	0.90	0.72	0.90	0.72
Total annual cost per train for electricity, £	2970	3450	1920	2040
Total annual cost per train-mile for electricity, *d*	13.2	15.3	9.6	10.2

97 Questions relating to the depreciation, maintenance and renewals of trains are of so wide-reaching a nature that it would be inappropriate to deal with them in this brief paper. For comparative purposes, however, the author does not believe that the instructiveness of his results will be impaired, if he takes at the rough figure of 15 per cent of the cost of the rolling stock, the annual charges for interest, depreciation, repairs and renewals. He will term these the annual charges for capital, depreciation, repairs and renewals per train, and as a check to indicate their general reasonableness, he will, in Table 14, also work out the corresponding values per train-mile.

98 In Table 15, are brought together the results of Tables 13 and 14.

99 Amongst the many and large remaining costs, there are none in which the adoption of the continuous system will entail greater costs per train than are incurred with the single-phase system.

100 It is well known that the gross receipts for three coach

TABLE 14 VALUES PER TRAIN MILE

Schedule speed, mi. per hr	30		22	
Average distance between stops, mi	1.32		0.88	
Designating number	I	II	III	IV
System	continuous	Single-phase	continuous	single-phase
Total cost of train, from Table 9, £	9475	15655	7515	11325
Percentage taken for obtaining annual capital charges, per cent	15	15	15	15
Annual charges per train for capital depreciation repairs and renewals, £	1420	2350	130	1700
Annual charges per train-mile for capital depreciation, repairs and renewals, *d*	9.31	10.43	5.65	8.55

trains on services of this character, are usually of the order of from 40*d*. to 60*d*. per train-mile. Let us fix our attention on a case where the gross receipts are 50*d*. per train-mile. It is evident from the results in the lowest horizontal line of Table 15 that in such a case, whatever be the net profits, they will be less if the single-phase system is used than if the continuous system is used. The percentage of the gross receipts which could be set aside as profits, would for the 30 mi.

TABLE 15 RESULTS OF TABLES 13 AND 14

Schedule speed, mi. per hr	30		22	
Average distance between stops, mi	1.32		0.88	
Designating number	I	II	III	IV
System	continuous	single-phase	continuous	single-phase
Total annual cost per train, for electricity, £	2970	3450	1920	2040
Annual charges for capital, depreciation, repairs, and renewals, per train, £	1420	2350	1130	1700
Sum of above two annual outlays, per train, £	4390	5800	3050	3740
Cost per train-mile, for electricity, *d*	13.2	15.3	9.6	10.2
Annual charges for rolling-stock, per train-mile, *d*	6.31	10.43	5.65	8.55
Sum of above two outlays per train-mile, *d*	19.51	25.73	15.25	18.75
Amount by which the single-phase train costs more per train-mile than the continuous-electricity train, *d*	6.22		3.5	

per hr., one-stop per 1.32 mile service, be $\frac{6.22 \times 100}{50} = 12.45$ per cent greater with the continuous than with the single-phase system. For the 22 mi. per hr., one stop per 0.88-mile service, they would still be greater by $\frac{3.5 \times 100}{50} = 6.7$ per cent. It is common knowledge that suburban traffic is at present very unremunerative, although this is not always obvious from balance sheets where the profits shown are usually very largely from main-line and goods traffic. Confining our attention to the suburban traffic, it appears that while there may be a few services in which the margin in favor of electrification is great enough to stand the higher cost of the single-phase system, there are many in which the great difference which the author has shown as existing between the two systems would make all the difference between commercial success and commercial failure.

101 The subject is a large one with many important aspects. This investigation, however, clearly shows that the selection of the electrical system and also the determination of the service to be provided as regards schedule speed, distance between stations and intensity of traffic, are all matters demanding the most careful attention and that they are interdependent. It is evident from the nature of the case, as illustrated by the problems the author has worked out, that the more severe the service and the more intense the traffic, the greater is the superiority of the continuous system. But it is also demonstrated that even for systems for such moderate severity as 22 mi. per hr. and one stop per 0.88 mile, and even when the intensity of traffic is only one train every 12 to 15 minutes in each direction, the superiority of the continuous system is still very substantial. It is, however, precisely for intense traffic and for severe services, that is, for services exceeding the limits amenable to steam-locomotive methods, that electricity is preëminently applicable.

102 A point of considerable interest, disclosed by a comparison of the values in the penultimate horizontal line in Table 15, is that, with the continuous system, the components of the total cost per train-mile, which he has considered, are 28 per cent greater (since $\frac{19.51}{15.25} = 1.28$) for the 30 mi. per hr., one stop per 1.32 mile service, than for the 22 mi. per hr., one stop per 0.88 mile service, while with the single-phase system, the cost per train-mile is 37 per cent greater (since $\frac{25.73}{18.75} = 1.37$) for the former than for the latter service. This is another point of view from which the greater appropriateness of the continuous system for severe services is apparent.

103 With the object of basing his comparisons on thoroughly authenticated cases, the author has taken for the continuous-electricity services, roads employing pressures of some 600 volts at the trains.

There are, however, now a considerable number of roads employing a pressure of 1200 volts with conspicuous success; indeed, in some of these instances, single-phase equipments have been replaced by 1200-volt continuous-electricity equipments. As early as 1904 the author[1] urged the advantages of doubling the customary pressure for continuous-electricity traction systems, and based his comparisons on the precise lines which are now being so successfully adopted. Upwards of a dozen roads have now adopted the 1200-volt continuous-electricity system of traction. This system effects distinct economies over the 600-volt system and very appreciably accentuates the contrast between the continuous-electricity system and the single-phase system.

[1] Electrical Review, vol. 54, pp. 693–765.