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MINISTRY OF TRANSPORT.

REPORT OF THE COMMITTEE  
ON  
MAIN LINE RAILWAY ELECTRIFICATION  
1931.



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MINISTRY OF TRANSPORT.

COMMITTEE ON MAIN LINE RAILWAY ELECTRIFICATION.

---

*Members of Committee:*

The Right Hon. Lord WEIR OF EASTWOOD, *Chairman.*

Sir RALPH WEDGWOOD, C.B., C.M.G.

Sir WILLIAM McLINTOCK, G.B.E., C.V.O.

*Secretary:*

Colonel A. C. TRENCH, C.I.E., R.E. (ret.)

STATEMENT OF EXPENDITURE.

The expenditure incurred by the Committee including the estimated cost of printing and publishing this report is £5,456.

34806

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(References are to paragraph numbers.)

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- V. Report by Messrs. Mers and McLellan on the Electrification of a portion of the L.M.S. Rly.

From no mere precedent or tradition do we pay our tribute to our Secretary, Colonel Trench, who has been indefatigable in the interests of thoroughness, invaluable as regards the technical aspect and happy in his unfailing courtesy, and to whom we extend our united thanks and appreciation.

We have the honour to be,

Sir,

Your obedient Servants,

WEIR, *Chairman*.

R. L. WEDGWOOD.

WILLIAM McLINTOCK.

A. C. TRENCH, *Secretary*.

24th March, 1931.

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APPENDIX I.

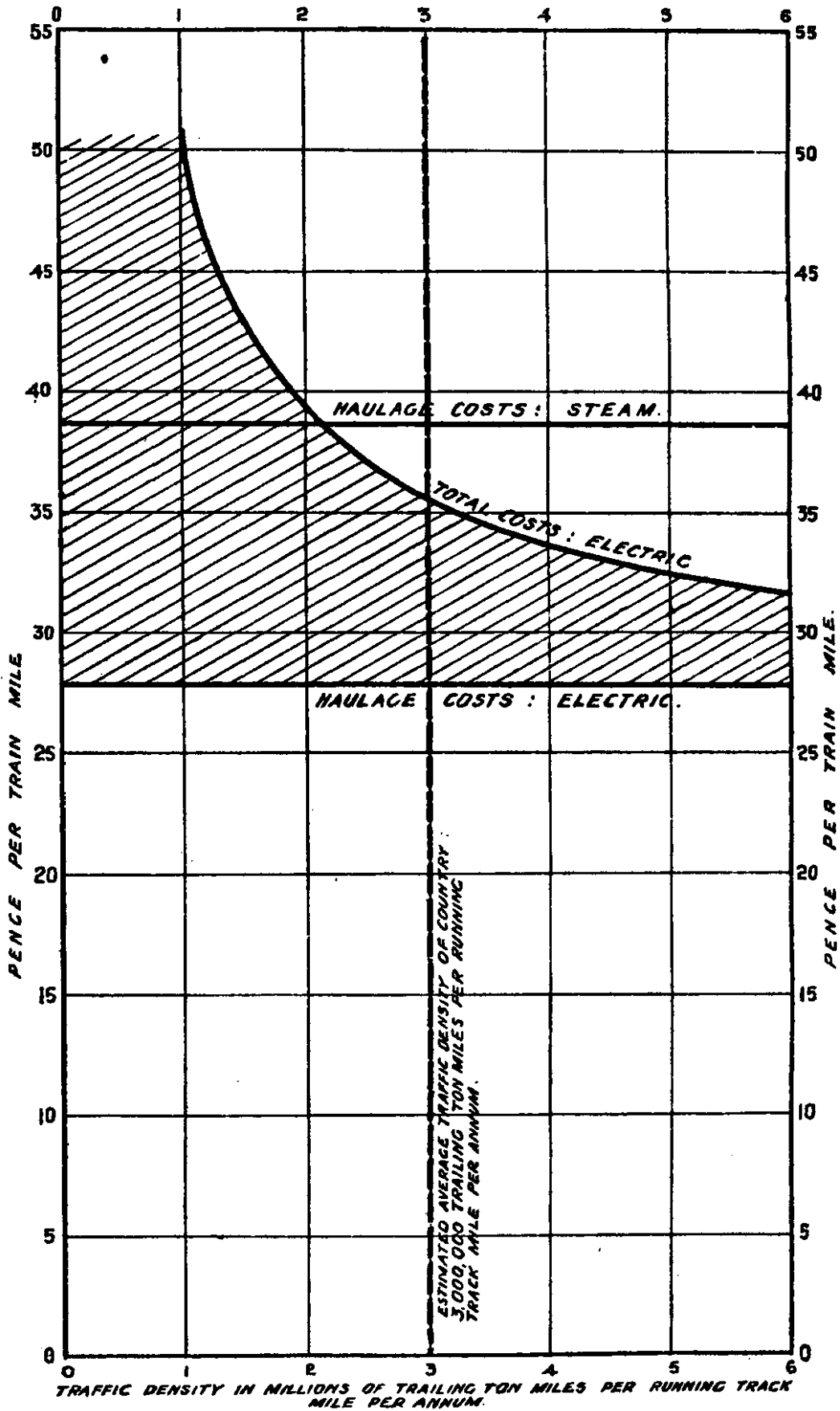
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LIST OF WITNESSES.

Sir John Aspinall.  
 Sir Philip Dawson, M.P.  
 Sir Andrew Duncan.  
 Sir Henry Fowler, K.B.E.  
 Mr. H. N. Gresley, C.B.E.  
 Sir Brodie Henderson, K.C.M.G., O.B.  
 Mr. Frank Hunt, C.V.O.  
 Mr. Herbert Jones.  
 Mr. J. M. Kennedy.  
 Mr. F. Lydall.  
 Mr. O. H. Merz.  
 Mr. J. Milne, C.S.I.  
 Sir Philip Nash, K.C.M.G., O.B.  
 Mr. H. W. H. Richards.  
 Mr. C. E. R. Sherrington, M.C.  
 Mr. Roger Smith.  
 Sir John Snell, G.B.E.  
 Sir Josiah Stamp, G.B.E.  
 Sir Herbert Walker, K.C.B.

# Diagram no I      Appendix II

## CURVE SHOWING SPREADING OF ELECTRIFICATION FIXED CHARGES BY INCREASING TRAFFIC DENSITY



## APPENDIX II.

## TRAFFIC DENSITY AS AFFECTING ELECTRIFICATION.

The important bearing which traffic density has upon the economics of Railway Electrification is indicated in Diagram I.

For the purpose of comparison with steam operation, the total cost of electric operation may be divided into two portions (a) haulage cost as described in para. 36, most of the items being less than the similar items for steam haulage, and varying almost directly with the number of train miles run, and (b) fixed charges, comprising interest, depreciation, maintenance and operation costs of the fixed equipment; within limits the cost of these is fixed per track mile and does not vary much whether the traffic be heavy or light.

It follows that with a dense traffic the fixed charges per track mile are divided among a larger number of trains, and the total cost of electric operation per train mile, i.e. haulage cost plus fixed charges, is reduced by an increase of traffic.

Diagram I, where the shaded area represents the fixed charges, indicates that for any traffic density above about 2.3 million trailing ton miles per running track mile per annum electrification should be profitable, and that the margin of profit increases with an increase of traffic.

The average traffic density of the railways of Great Britain is estimated at 3 million trailing ton miles per running track per annum. The elimination of lightly loaded branch lines etc. would of course increase the average density of the remainder. The average traffic density of the L.N.E.R. area investigated by Messrs. Merz and McLellan (see Map in Appendix IV) was found to be 4.3 million trailing ton miles per running track mile per annum.

*Notes on Diagram I.*

All costs are based on figures of Committee's estimates for General Electrification, para. 44, and on the assumptions made therein regarding supply of energy.

Haulage costs, steam and electric, include Items 1 to 10 of Table II (para. 44) with the addition of the full cost of renewals and interest on tractors. Cost of each train mile includes its proportion of shunting.

Fixed charges, electric, are estimated at £322 per running track mile per annum which figure includes interest, maintenance and renewals of electric track equipment, interest on alterations to way and works, and maintenance and operation of sub-stations. Charges on each running track mile include those on its proportion of siding track.

Haulage costs are calculated for 3,000,000 trailing ton miles (train ton miles plus shunting ton miles) per running track mile per annum, and assumed to be constant for other traffic densities. This is not strictly accurate but as the variable factors would have a generally similar effect on both steam and electric operation, they are disregarded for the purposes of this illustration.

Permanent way and similar items common to both systems are excluded.

Total train miles (1929) by steam traction, 373,000,000.

## APPENDIX III.

## POSSIBILITIES OF SUBURBAN ELECTRIFICATION.

Any scheme for the complete electrification of the railway system of this country would include the electrification of a considerable mileage of lines of a suburban character. On lines of this character passenger traffic readily responds to the stimulus of an intensified and accelerated service such as can be cheaply and readily provided under electric haulage. The additional revenue to be earned in this way would undoubtedly be substantial, and should be taken into account in any attempt to assess the secondary advantages of a general scheme of electrification.

Experience shows that, in order to secure and to cater for an additional volume of traffic, a heavier expenditure is necessary for suburban electrification as measured in cost per mile of track. Additional rolling stock must be purchased, car sheds and siding room provided, stations enlarged, and signalling modernised. Moreover extensive widenings and other alterations of running line accommodation are frequently found to be necessary. On the basis of some recent cases which may be taken as typical of London and provincial conditions this additional expenditure may be put at about £10,000 per track mile on the average. If the suburban track mileage of the country be taken as approximately 4,500 miles, we arrive at a total additional capital expenditure round about £45,000,000.

The intensification of the service also involves an increased operating expenditure which in the cases under notice amounted in round figures to £800 per track mile per annum. If these cases may be taken as typical, this item represents an addition of £3,600,000 to the current costs of suburban operation. Some allowance must also be made for the maintenance and renewal of additional tracks, bridges, signals, etc. This may be very roughly estimated at 1 per cent. on one-third of the total additional capital cost, or say £150,000 per annum.

To meet these extra annual costs and to remunerate the additional capital expended, one must look to the prospective growth in passenger traffic stimulated by an improved and intensified service. It is clearly a difficult matter to frame an estimate either as to increased volume of business or as to increased revenue. It may be anticipated that the growth of suburban traffic in the neighbourhood of provincial centres would not be so pronounced as it has proved to be in the neighbourhood of London. Allowance must also be made for the probable development of competing forms of transit, whether by road or by tube. An ultimate Revenue increase of 80 per cent. may perhaps be taken as a conservative estimate.

The revenue from suburban traffic as a whole, excluding areas already electrified, may be estimated as £12,000,000. An increase of 80 per cent. on this total would give an increased revenue of

*Deduct.*

Additional operating expenses	...	...	...	...	...	...	...	...	...	3,600,000
Maintenance and renewal of the additional Tracks, etc.	...	...	...	...	...	...	...	...	...	150,000
										<hr/>
										3,750,000
										<hr/>
Balance	...	...	...	...	...	...	...	...	...	5,850,000
										<hr/>

being a return of 13 per cent. on the additional capital of £45,000,000 as a contribution to strengthen the case for the complete scheme of electrification. There is inevitably a very large amount of conjecture involved in these figures, but on the whole the estimate may, we think, be taken as a reasonable anticipation of the return to be obtained from the additional capital expenditure involved.



## APPENDIX IV.

REPORT BY MESSRS. MERZ AND McLELLAN ON THE ELECTRIFICATION OF A PORTION OF THE LONDON AND NORTH EASTERN RAILWAY.

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## MAP OF ROUTES CONSIDERED.

July, 1930.

To

THE SECRETARY,

## THE RAILWAY ELECTRIFICATION COMMITTEE.

SIR,

We now have pleasure in submitting herewith our report on the electrification of a portion of the London and North Eastern Railway, which we have investigated in accordance with the Committee's instructions. The scheme includes a section of the main line from London to Doncaster and Leeds, and several branch lines in Lincolnshire. The report sets out in detail the traffic on the various lines to be dealt with, the proposed methods of working the traffic electrically, estimates of Capital Outlay on electrification, comparative estimates of steam and electric operation, and the financial result deduced from this comparison.

Summarised very briefly, the figures are as follows:—

Total Route Mileage is about	...	...	...	...	...	...	...	500
Total single track mileage, including yards and sidings, about	...	...	...	...	...	...	...	1,950
Trailing ton miles, per annum, are about	...	...	...	...	...	...	...	6,000,000,000
and the Engine miles	...	...	...	...	...	...	...	21,000,000
The net Capital Outlay is about	...	...	...	...	...	...	...	£8,646,000
The saving in working expenses is £624,630, representing 7.22 per cent. on the net Capital Outlay.								

This is subject to modification in the event of the price of coal rising or falling from the present level, the saving in the working expenses being increased or decreased for each rise or fall of 1s. per ton by £19,454, which is equivalent to 0.225 per cent. on the net capital outlay.

From this saving must be deducted the increase, if any, in the local rates payable by the Railway Company in respect of the electrical installation, including the substations, which, in the present circumstances, we have not attempted to estimate. The balance should be sufficient to pay the interest charges on the net Capital, with a small margin.

It will be noted that, as agreed with the Railway, no assumption has been made as to any increase in the traffic beyond that of last year. Further, although a large part of the passenger traffic and nearly all the goods traffic would be speeded up, no increase in the revenue consequent thereon has been assumed.

Although the statistics of mileage and traffic have been sub-divided under four sections, we have not attempted to sub-divide similarly the estimates of Capital Cost and Working Expenses. The traffic on the various sections is, to a certain extent, interdependent, and, if one or more sections were omitted from the complete scheme, fresh estimates would have to be prepared for the remaining sections. The figures contained in the Report shew that the traffic varies widely on the different lines. Thus, for example, although the London-Leeds section has only one-third of the total route mileage, and only one-half of the single track mileage, the traffic on this section, expressed in trailing ton miles, or engine miles per annum, is two-thirds of the total. The cost of the electrical installation, apart from locomotives, being approximately proportional to the single track mileage, it might appear that the electrification of this section alone would shew a better return on the capital expenditure than the complete scheme. As, however, the exclusion of any section might involve a reduction in the traffic on the remaining sections that could be profitably hauled electrically, it is impossible to say without a fresh investigation what would be the result of electrification of individual sections.

Much of the material necessary for such subdivision is available, and the separate estimates could without difficulty be worked out, but would take some time. For the present, we have confined our attention to the complete scheme in accordance with the Committee's instructions.

We trust that the Committee will find in this Report all the information which they require, but we are at their disposal to elucidate any points on which they would like further explanation.

Yours faithfully,

MERZ AND McLELLAN.

LONDON AND NORTH EASTERN RAILWAY.  
REPORT ON ELECTRIFICATION.

In this report we give the results of our investigation into a scheme of electrification for a considerable section of the London and North Eastern Railway. The section, which is shown in the map accompanying this Report, comprises the main line from King's Cross to Doncaster and Leeds, the branches from Grantham to Nottingham, Boston and Lincoln, the line from Doncaster to March via Lincoln, Sleaford and Spalding, the line from Peterborough to Grimsby and Cleethorpes via Boston, the Mablethorpe and Skegness branches, and the connecting line from Coningsby Junction to Bellwater Junction.

This group of lines has been selected with two objects in view. First, the Committee desired that the scheme investigated should be fairly representative of the British Railways as a whole, and not merely a scheme for electrification of a particular section on which, due either to very dense traffic or to the existence of steep gradients or long tunnels or to other local conditions, the conversion to electric working would present obvious advantages. Second, it was important to base all calculations on statistics as to traffic and working expenses which could be taken out from actual records without having to make more assumptions than was absolutely necessary to allow for the continued running of some of the traffic by steam and the retention of some running sheds, coaling plant, watering arrangements, etc., for the maintenance and operation of steam locomotives.

TABLE I.  
ROUTE AND SINGLE TRACK MILEAGES.

Section No.	Description.	Route Mileage.	Single track mileage.		Sidings clear of Running Lines.	Single Track Mileage.				Section Totals.	
			Running Lines.	Sidings in Running Lines.		Traffic Sidings.	Traffic sidings at intermediate stations.	Traders sidings at all stations.	Loco. and Engineers sidings at all stations.		
1	King's Cross-Leeds, excluding lines already included under the Suburban Scheme from King's Cross to Welwyn Garden City	165.1*	644.8	22.3	King's Cross...	22.39					
					Holloway ...	3.74					
					Finsbury Park	14.21					
					Harringay ...	17.10					
					Hornsey ...	9.61					
					Wood Green...	2.76					
					Hatfield ...	4.50					
					Knebworth & Langley ...	4.04					
					Hitchin ...	5.53					
					Arlesley ...	2.33					
					Biggleswade...	3.81					
					Sandy ...	2.45					
					Huntingdon...	3.50					
					Fletton ...	1.95					
					Peterboro' & New England	36.55					
					Grantham ...	4.77					
					Newark ...	4.24					
Retford ...	4.44										
Doncaster ...	34.10										
Wrenthorpe...	8.30										
Ardsley ...	11.20										
					201.52	60.89	33.20	73.81	369.42		
2	March-Doncaster ...	98.2	210.93	7.41	Lincoln ...	10.87					
					Whitemoor (5 reception roads only)...	2.11					
					Gainsborough	2.65					
					15.63	27.37	3.87	4.90	51.77		
3	Grantham-Nottingham. Grantham-Lincoln-Boston ...	73.7	160.88	6.57	Colwick ...	46.27					
					Sleaford ...	3.29					
					Boston ...	17.20					
					66.76	19.20	10.61	3.27	99.84		
4	Peterboro'-Grimsby-Cleethorpes and branches. Lincoln-Boston ...	155.0	296.10	6.63	Spalding ...	4.70					
					Cleethorpes ...	2.83					
					Skegness ...	5.19					
					12.72	48.31	6.57	.63	68.23		
					296.63	155.77	54.25	82.61	589.26		

\* Not including King's Cross to Welwyn Garden City, a distance of 20.6 miles.

Both these objects have been fulfilled in the selection of lines dealt within this Report. The traffic between London and Doncaster is very heavy, whereas on several of the lines in Lincolnshire the traffic is very light. The sections included constitute the bulk of the old Great Northern Railway, and are still for most purposes worked as a self-contained group.

The maximum gradient on any part of the scheme is 1 in 80 on the Doncaster—Leeds section, but on the majority of the lines the gradients are easier than this. For example, on the main line between King's Cross and Doncaster, apart from short stretches of 1 in 100, the maximum gradient is 1 in 200.

We have been advised by the Railway as to the goods yards which, for traffic and other reasons, should be considered as forming a part of the Scheme, the most important being King's Cross and others in the London area, Peterborough, Colwick, Doncaster and Wrenthorpe and Ardsley in the Leeds area. Certain other yards adjacent to the section are omitted from the Scheme. An example of this is Whitemoor, where half of the reception roads only have been included.

In accordance with our instructions we have assumed that the suburban services from King's Cross to Welwyn Garden City have already been electrified, and that no provision need be included in the present scheme for working this traffic or for the equipment of the lines or for the power supply arrangements necessary for the suburban scheme. We have therefore only allowed in our estimates for the equipment of those tracks in the London area which are not required for suburban working, and for the additional plant in the substations necessary for the main line traffic and the work in the goods yards.

The route and single track mileages are given in Table I.

#### Traffic Statistics.

For the compilation of the traffic statistics on which the comparison of steam and electric operation has been worked out, particulars of all trains were taken out from the records for certain weeks in the year 1929, which were selected by the Railway Officers as being typical of the conditions at different seasons. From the figures so obtained the totals for the year were compiled. The statistics are set out in Table II.

TABLE II.

TRAFFIC STATISTICS.

Summary of Trailing Ton Mileages.

Section.	London—Leeds (excluding Suburban Traffic as far as Welwyn Garden City).	Doncaster— March.	Grantham— Nottingham and Grantham— Lincoln and Boston.	Peterboro', Grimsby and Cleethorpes Skegness branch, Mablethorpe Loop, Lincoln— Boston, Coningsby— Bellwater.	Total.
<b>STEAM.</b>					
<b>PASSENGER.</b>					
Loaded ... ..	1,440,461,815	116,286,021	84,048,366	175,480,058	1,816,276,260
Empty ... ..	51,454,505	3,488,580	2,521,452	5,264,401	62,728,938
Shunting by train engine ...	1,820,850	860,350	611,800	2,428,100	5,221,100
Total ... ..	1,493,737,170	120,134,951	87,181,618	183,172,559	1,884,226,298
<b>GOODS.</b>					
Loaded and Empty ... ..	2,302,959,581	900,825,887	336,858,938	287,061,164	3,827,705,570
Shunting by train engine ...	25,724,852	6,909,722	8,624,708	6,761,125	43,020,407
Total ... ..	2,328,684,433	907,735,609	340,483,646	293,822,289	3,870,725,977
<b>SHUNTING BY SHUNTING ENGINES.</b>					
Passenger ... ..	28,396,350	980,200	237,300	353,450	29,967,300
Goods ... ..	107,992,778	13,235,554	19,917,688	14,361,044	155,507,064
Total ... ..	136,389,128	14,215,754	20,154,988	14,714,494	185,474,364
SHED SHUNTING ... ..	64,748,250	15,518,850	4,554,300	4,559,400	89,380,800
BALLASTING ... ..	14,479,761	2,618,300	2,022,897	2,534,442	21,655,400
DEPARTMENTAL ... ..	8,508,550	449,550	849,150	632,600	10,439,850
Total ... ..	4,046,547,292	1,080,673,014	455,246,599	499,435,784	6,061,902,689
<b>ELECTRIC.</b>					
All figures except "Shed Shunting" as above.					
SHED SHUNTING ... ..	6,474,825	1,551,885	455,430	455,940	8,938,080
Total ... ..	3,988,273,867	1,046,706,049	451,147,729	495,332,324	5,981,459,969

*Traffic Working.*

In general, passenger trains may be worked electrically in two alternative ways, viz., by locomotive-hauled trains and by multiple-unit trains consisting of self-propelled or motor coaches and trailers. There are advantages in each method. Where trains have to run for long distances at high speeds (up to 75 and 80 miles per hour on British railways), and may have to run over sections where electric working is not in force, it is advantageous, if not actually necessary, to use locomotives. There are, however, on all sections a number of passenger trains which stop frequently and have only a limited length of run, and for such trains the multiple-unit system is well adapted by reason of its elasticity in operation and the improved acceleration at starting.

The division between these two alternative methods of working the traffic on the sections under consideration has been carefully examined by the Superintendent, who has given us a list of the trains that are not suitable for multiple-unit working. The use of multiple-unit trains would be much more extensive on the branch lines than on the main line from London to Leeds. This is clearly shewn by the statistics of passenger train mileage in Table IV. The proportion for the main line is about 65 per cent. locomotive-hauled to 35 per cent. multiple-unit, and for the branch lines 15 per cent. locomotive-hauled to 85 per cent. multiple-unit.

In accordance with instructions, we have assumed no acceleration of the long-distance passenger trains hauled by locomotives. For the multiple-unit trains advantage has been taken of the rapid starting which is a feature of this system, and the average speed has been increased by 10 to 20 per cent. compared to present steam timings. For example, a train from King's Cross to Peterborough, stopping at 15 intermediate stations, now takes 2 hours 32 minutes; the electric timing, allowing for the same stops, would be 2 hours 8 minutes. Similarly, a train from Grantham to Boston, stopping at 5 intermediate stations, now takes 62 minutes; the electric timing would be 46 minutes. The motors would be designed for a maximum running speed not exceeding 60 miles per hour.

Apart from the regular passenger trains, there are from time to time a number of excursion trains. These would be hauled by electric locomotives, and, as specially high speeds are not essential, the stock of passenger locomotives would, so far as necessary, be supplemented by locomotives of a different class normally employed in hauling express goods. These locomotives would be suitable for a maximum speed of 60 miles per hour, and the average speed for a 12-coach train on a non-stop run, for example, between Peterborough and King's Cross would be about 50 miles per hour.

We have given careful consideration, with the officers of the Railway, to the working of the goods and mineral trains in order to see how far the advantages offered by electric operation can be realised under the special conditions prevailing in this country. These advantages arise from the practically unlimited locomotive power which can be provided without exceeding the restrictions which limit the dimensions, the weight per axle and the concentration of weight of the locomotives, and, but for other restrictions, would enable heavier trains to be hauled at greatly increased speeds.

So far as train weights are concerned, it is not considered advisable, on account of the strength of the standard draw gear, to make any increase in the maximum loads now hauled. The majority of trains are, however, much below the maximum in weight, and in so far as this is due to the limited capability of the steam locomotives now in use it would seem practicable to increase the average weight and thereby reduce the number of trains. This has been done in various schemes of electrification already carried out, e.g., in South Africa and India, with consequent gain to the working costs. We understand, however, that on the L.N.E.R. the weights of goods trains are settled partly by the lengths of refuge sidings and partly by the inconvenience or difficulty in delaying the despatch of trains from the marshalling yards until full loads have been made up. Our calculations have therefore been based on the present service so far as train weights and number of trains are concerned.

By reason of the same characteristic of electric traction, viz., the practically unlimited locomotive power available, it is possible to increase considerably the speeds of goods and mineral trains. In practice there are various factors which make it inadvisable to run unbraked trains at more than about 35 miles per hour, especially the liability for axle boxes to become overheated, and the difficulty of stopping trains when running down gradients by the braking power of the locomotive and the brake van alone. It is, however, quite practicable, given sufficiently powerful locomotives, to haul trains up the gradient at a much higher speed than is feasible to-day with steam locomotives. We have therefore assumed, with the concurrence of the officers of the Railway, that all unbraked goods trains would be hauled up the ruling gradient on each section at about 27 to 28 miles per hour, and that the speed on the level would be limited to about 33 miles per hour. Down the ruling gradient the speed would be reduced to such a value that the train could be brought to a standstill within the distance between the point where the distant signal is sighted and the home signal. With a mineral train of the maximum weight this speed would be about 25 miles per hour. The average speed for all non-stop unbraked goods and mineral trains would thus be about 30 miles per hour. This may be compared with the present-day speeds for trains of different classes between London and Peterborough as follows:—Class A. 23 to 24 miles per hour and Classes B. and C. 17 to 20 miles per hour.

The limitations mentioned above do not apply to express goods trains composed of wagons fitted with continuous brakes and oil-lubricated axle boxes. The present practice is to run these trains at speeds not exceeding 60 miles per hour for No. 1 Express goods, which consist only of braked vehicles, and 45 miles per hour for No. 2 Express goods, which contain only a certain proportion of braked vehicles. In our calculations we have adhered to these figures. For the No. 1 Express goods the electric timings would be the same as at present, but the average speed of the No. 2 Express goods would be somewhat increased.

Fresh timings in accordance with the foregoing particulars have been worked out for trains of all classes (except the long-distance locomotive-hauled passenger trains) on all sections. With these timings the Superintendent's Department have prepared a new set of time tables which form the basis for the calculation of several items in the estimates of Capital Outlay and Working Expenses. It is interesting to remark that these new time tables show an annual saving in the time on journey (taking into account week-days only) of 24,087 hours (or 18.78 per cent.) for multiple-unit passenger trains, and 116,833 hours (or 18.0 per cent.) for goods and mineral trains.

The mileage worked by steam and electric locomotives are set out in Table III. and IV. As explained below, with the locomotives proposed all trains would have sufficient haulage power to run to schedule times without assistance. There would, therefore, be no necessity to include in the figures for engine mileage any allowance for "Assisting required." These figures, therefore, have been omitted for electric working of both passenger and goods traffic.

The figures for "shunting by shunting engine," "ballasting" and "departmental" are unaltered, but there would be a substantial reduction under electric working of the "shed shunting." A large part of this work under present conditions is the movement of locomotive coal wagons; the remainder is the movement of "dead" engines. The former would, of course, be completely eliminated; and the latter considerably reduced, partly because shed work with electric locomotives is much less than with steam engines, and partly because electric locomotives generally move about under their own power. We have, therefore, with the agreement of the Railway, reduced the trailing ton miles and the engine miles under this heading to 10 per cent. of the steam figures.

TABLE III. LOCOMOTIVE WORKING. (Steam).  
*Summary of Engine Miles.*

Section.	London-Leeds (excluding Surburban Traffic as far as Welwyn Garden City).	Doncaster- March.	Grantham- Nottingham, and Grantham- Lincoln and Boston.	Peterboro'- Grimby and Cleethorpes Skegness branch Mablethorpe Loop, Lincoln- Boston, Coningsby- Bellwater.	Total.
<b>PASSENGER.</b>					
Train ... ..	5,223,505	642,389	657,521	1,107,918	7,631,333
Shunting by train engines	36,417	7,207	12,236	48,562	104,422
Light ... ..	206,961	10,221	45,967	66,764	329,913
Assisting required ...	84,447	—	55	2,035	86,537
Assisting not required ...	6,060	660	—	4,805	11,525
<b>Total ... ..</b>	<b>5,557,390</b>	<b>660,477</b>	<b>715,779</b>	<b>1,230,084</b>	<b>8,163,730</b>
<b>GOODS.</b>					
Train ... ..	4,445,290	1,634,615	726,946	608,862	7,413,713
Shunting by train engines	381,901	102,579	53,811	100,373	638,664
Light ... ..	389,478	76,220	96,223	51,332	613,253
Assisting required ...	11,158	617	11	—	11,786
Assisting not required ...	491	10,427	205	2,840	13,963
<b>Total ... ..</b>	<b>5,228,318</b>	<b>1,824,458</b>	<b>877,196</b>	<b>761,407</b>	<b>8,691,379</b>
Shunting by shunting engines.	2,904,496	293,785	414,980	309,608	3,922,869
Shed shunting ... ..	431,655	103,459	30,362	30,396	595,872
Ballasting ... ..	144,798	26,183	20,229	25,344	216,554
Departmental ... ..	170,171	8,991	16,983	12,652	208,797
<b>TOTAL ... ..</b>	<b>14,436,828</b>	<b>2,917,353</b>	<b>2,075,529</b>	<b>2,369,491</b>	<b>21,799,201</b>

#### *Electric Locomotives.*

For hauling the heavy long distance passenger expresses we should propose a locomotive with four driving axles and a leading and trailing truck, having a total weight of about 110 to 115 tons, of which 72 tons would be on the drivers. This locomotive would be suitable for a normal maximum operating speed of 75 miles per hour, and at this speed would be capable of exerting a tractive effort of about 7,000 lb., or a drawbar pull (when running on the level) of 4,525 lb. It would be equipped with motors having an aggregate capacity (on the one hour rating) of about 2,400 h.p. As the centre of gravity would be comparatively high, all running parts completely balanced, and the motors fully spring borne, this locomotive would be easier on the track than any existing steam locomotive. It would be capable of working the heaviest trains to their present timings with a comfortable margin in hand to meet traffic delays, or bad weather conditions. It would be rather more powerful than necessary for the lighter expresses of say 350 tons, but we do not think there would be any economy in providing two different classes of high speed passenger engine as the slight extra cost of making them all alike would be offset by the better utilisation of the one

TABLE IV. LOCOMOTIVE WORKING. (Electric).  
Summary of Engine Miles.

Section.	London-Leeds (excluding Suburban Traffic as far as Welwyn Garden City).	Doncaster- March.	Grantham- Nottingham, and Grantham- Lincoln and Boston.	Peterboro' Grimsby and Cleethorpes Skegness branch, Mablethorpe Loop, Lincoln- Boston, Coningsby- Bellwater.	Total.
<b>PASSENGER.</b>					
Train.					
Locomotive ... ..	3,414,036	140,191	47,454	222,203	3,823,884
Multiple unit ... ..	1,809,469	502,198	610,067	885,715	3,807,449
Shunting by train engines.					
Locomotive ... ..	24,000	1,570	1,836	9,700	37,106
Multiple unit ... ..	12,417	5,637	10,400	38,862	67,316
Light ... ..	135,000	2,240	3,300	13,600	154,140
Assisting not required ...	4,000	140	—	950	5,090
Total ... ..	5,398,922	651,976	673,057	1,171,030	7,594,985
Goods.					
Train ... ..	4,445,290	1,634,615	726,946	606,862	7,413,713
Shunting by train en- gines.	381,901	102,579	53,811	100,373	638,664
Light ... ..	389,478	76,220	96,223	51,332	613,253
Assisting not required	491	10,427	205	2,840	13,963
Total ... ..	5,217,160	1,823,841	877,185	761,407	8,679,593
Shunting by shunting engines.	2,904,496	293,785	414,980	309,608	3,922,869
Shed shunting ... ..	43,165	10,345	3,036	3,039	59,585
Ballasting ... ..	144,798	20,183	20,229	25,344	216,554
Departmental ... ..	170,171	8,991	16,983	12,652	208,797
Total ... ..	13,878,712	2,815,121	2,005,470	2,283,080	20,982,383

class which enables the number of locomotives to be kept down to the minimum. Advantage might be taken of this extra power either to accelerate the lighter trains or to put in several intermediate stops while maintaining the present overall timing. For example, a train which now runs non-stop from King's Cross to Peterborough in 83 minutes could stop for 2 minutes at 4 intermediate stations, and still keep time. The electrical control of the motors would provide for several running speeds, and the locomotive could, if desired, work intermediate trips with goods trains of any class up to about 600 tons in weight at the speeds for which the vehicles are suitable.

The weights of goods train are so various, including the heaviest minerals and the lightest pick-up goods, that it would be uneconomical to provide only one class of goods locomotive. For unbraked goods, the weight of the locomotive available for braking must be sufficient to hold the train on a falling gradient, and bring it to rest at any signal against it. The heaviest trains consisting of loaded mineral wagons have a weight of 1,220 tons. For such trains a locomotive of 144 tons would be suitable to provide for the speeds mentioned above. Such a locomotive would have eight axles with 18 tons per axle, and each wheel would be fitted with two brake blocks. This would enable a 1,220-ton train, running down the ruling gradient of 1 in 200 at 25 miles per hour, to be brought to rest in 1,000 yards, even in wet weather.

According to the figures taken out for the sections considered the great majority, viz., 79 per cent., of goods trains are less than 600 tons in weight. Of the remaining 21 per cent., more than half do not exceed 900 tons. In order to deal economically with this diversity of traffic, we propose that two classes of locomotive should be provided, viz., Class A having two 4-wheel bogies, and Class B having two 6-wheel bogies. In both classes all axles would be driving axles, and the weight per axle would be 18 tons. Locomotives of Class A would be designed for multiple-unit working, and two such locomotives coupled together and controlled by a single driver would be used for trains of more than 900 tons. Trains not exceeding 600 tons on sections where the ruling gradient is not steeper than about 1 in 200 would be hauled by single Class A locomotives; trains weighing from 600 to 900 tons, and lighter trains on sections where the gradients are more severe than 1 in 200 would be hauled by single Class B locomotives. All locomotives of both classes would be equipped with the same motor, which would in all essential details be identical with the motors of the passenger locomotives.

These Class A and Class B locomotives would not be suitable for working express goods trains. They would not be designed for any higher train speed than 35 miles per hour, and would not be equipped with vacuum pumps for the operation of train brakes. We would propose, therefore, that the express goods trains should be hauled by modified Class B (6-axle) locomotives, referred to below as Class B1, the modifications consisting only in an alteration to the ratio of the gearing between the motors and the driving axles, and in the provision of an electrically driven vacuum

pump. These modified locomotives would be suitable for a maximum train speed of 60 miles per hour, and would have sufficient tractive effort for all express goods trains as now made up on all sections. Some of them, as already explained, would be used for hauling excursion trains, and when necessary would be fitted with boilers for heating the coaches.

There are throughout the system a considerable number of shunting locomotives employed in the goods yards at or near the principal stations and for shunting passenger trains. We have made a careful study of the question how to carry on this work most economically under electric conditions. At most places there are some tracks which are very seldom used by any locomotive, and in order to avoid unnecessary expenditure on the overhead line equipment for such tracks the suggestion has been made to employ a sufficient number of battery locomotives suitable for taking power from the overhead line when running on equipped tracks and from the battery when on tracks without overhead equipment. Such locomotives are, however, costly and comparatively inefficient, and in the conditions prevailing in the yards included in the present scheme we consider it preferable to equip all tracks on which locomotives may have to run, however seldom, and provide only electric shunting locomotives of the simplest design. These would be of the four-axle double-bogie type, weighing about 60 tons, and equipped with four 180 h.p. motors, giving a tractive effort of about 20,000 lbs. The control and grouping of the four motors would enable the locomotives to work economically at the speeds usual in shunting yards, and also at the higher speeds necessary when hauling trains from one yard to another, or from the carriage sidings to the terminal stations.

#### *Electrical System and Track Equipment.*

In accordance with the recommendation of the Ministry of Transport Committee on Electrification we have assumed that the 1,500 volt direct current system would be adopted, and that the track equipment would consist of overhead wires with the running rails bonded for the return circuit.

For all running lines the overhead equipment would be of the catenary design, with a copper section depending on the distance between substations, the number of tracks, the density of the traffic and the gradients. The accommodation of the live lines in tunnels and under low bridges has been the subject of special study by the Engineer on information which we have supplied. We are informed that there are no insuperable difficulties, and his estimate for the necessary alterations is included in the Capital Estimates, Table V. The equipment of tracks in yards would be of a simpler and cheaper design, as in such places working speeds are always low.

The structures supporting the overhead line tend to obscure the view of the signals, especially on tangent track, where the track equipment as seen from the driving cab of the locomotive appears as a sort of tunnel. Experience on some electrified railways shows that very little alteration to the signals has been necessary, but it is considered advisable for this electrification scheme, on account of the short block sections and the high running speeds, to remodel all main line running signals and fit them with Leebly signal lights and on the less important branches to carry out such alterations and relocations as might be found necessary.

As the running rails would form part of the circuit for the traction current, it would no longer be possible to use the present system of direct current track circuiting. All relays and fittings would therefore be changed for others suitable for operation with alternating current. The supply of power for this purpose would be provided at the substations and distributed by an insulated cable.

All communication circuits which now work with an earthed return would have to be changed over to an insulated return, otherwise the traction current returning to the substations by the rails and the earth would cause serious interference. Apart from this, no extensive alterations, such as cabling all the circuits, would be necessary, as there would be no high voltage alternating current overhead lines along the track, and the ripples in the direct current carried by the contact lines would be so small that there would be no appreciable interference with the transmission of speech or signals. It may be mentioned, as bearing on this point, that in the main line electrification schemes in India and South Africa, in both of which the direct current system is in use, it has not been found necessary to cable the communication circuits which run parallel to the electrified lines. The Engineer has prepared an estimate of the cost of carrying out the necessary alterations, and his estimate is included in the item "Alterations to Ways and Works" in Table V.

#### *Power Supply and Substations.*

In accordance with the Committee's instructions, we have assumed for the purposes of this report that the Railway would purchase from the Central Electricity Board all power for traction as direct current at 1,500 volts, and for other purposes as three-phase or single-phase alternating current at 6,600 volts, or other suitable pressures, and the Board have requested us to base our calculations on a rate of 0.5d. per unit, subject to the Railway being responsible for the maintenance and operation of the substations, and for the payment of local rates, if any, thereon. This figure is given on the assumption that the load factor of the total demand would be not less than 50 per cent. Our experience with other electric railways shows that such a load factor would be obtained. The supply agreement would contain a coal clause providing for an increase or decrease in the price per unit corresponding to a rise or fall in the price of coal; the effect of any such adjustment is referred to below on page 46.

We have carefully considered the arrangements that will have to be made by the Railway for maintenance and operation, under the assumption, to which we understand the Board agree, that all substations would be equipped with automatic and remote control apparatus. The complete electrified section would be divided into several areas, and in each area there would be a Power Control office from which any converting set in any substation in the area would be started up or shut down and any feeder switch opened or closed. Each of these offices would be in charge of Power Controllers working in shifts, and would be connected by pilot circuits to all substations and track sectioning switch cabins in the area controlled therefrom, and by telephone with the



other offices of the organisation and of the traffic control. The pilot circuits would not only enable the Power Controller to carry out all necessary operations, but would also indicate to him the condition of the various converting sets and the positions, whether open or closed, of all switches. In the event of any trouble occurring, the Controller would communicate at once with the maintenance staff.

#### *Auxiliary Power Supplies.*

Apart from the main converting sets which deal only with the supply of direct current at 1,500 volts for traction purposes, each substation would be equipped with one or more static transformers for the supply of power for auxiliary purposes, such as signalling, station and yard lighting, capstans, cranes and pumping. An insulated cable, running the whole length of the track on the main line and on all branches would be connected to the auxiliary transformers in the substations, and would be tapped wherever necessary for the new signal lights and track circuits, and for lighting and power purposes at intermediate stations.

At many places electric power is already provided, at others gas and oil are in use. In the former few alterations would be necessary to adapt the installation to the new supply. In the latter, the stations would have to be wired and the necessary switchgear and fittings installed, and in some places where on the present system the consumption of gas or oil is very small, and the annual cost is very low, it would be difficult to prove any financial advantage by the conversion. This matter has been investigated by the Electrical Engineer for the purpose of this Report, and his estimates are included in the Tables of Capital Outlay and Working Expenses.

#### *Heating and Lighting of Passenger Trains.*

In all schemes for the electrification of main line railways, it is necessary to take into account the provision of means for heating passenger coaches in place of the steam previously supplied by the locomotive boiler. The most natural method is to fit all coaches with electric heaters, and this is always done on multiple-unit trains. It would, however, be a long time before all main line stock could be so fitted, as, due to interchange of traffic on different lines, there are on many trains coaches from other railways. There is also the possibility that coaches normally in use on the electrified sections may have to run on to lines where there is not enough traffic to justify electrification. It is clear, therefore, that provision must be made for supplying steam for heating, and the present heaters must be retained on all the Company's coaches which may still at times be hauled by steam locomotives.

All electric locomotives used for hauling passenger trains would, therefore, be fitted with a boiler of suitable capacity. Such a boiler may be fired by coke or oil fuel, or may be electric. The latter is rather more expensive in running cost, but in view of its advantages in regard to cleanliness, simplicity and absence of fire risk, it is, in our opinion, to be preferred. The alternative would be to attach to the locomotive during the winter months a special wagon fitted with a coke, or oil-fired boiler, but this would be very inconvenient from the traffic point of view, especially at terminal stations.

For the multiple-unit stock which does not run off the electrified lines, and which always has a supply of power available, there would be no objection to electric heating, and provision is made in the estimates for wiring and fitting all multiple-unit coaches with suitable heaters.

For the lighting of passenger trains we should propose to retain the present system except on the multiple stock which would be wired for taking supply from the motor coaches, in accordance with the usual practice.

TABLE V.

ESTIMATES OF CAPITAL EXPENDITURE.

*Excluding Expenditure on Locomotives and Multiple Unit Train Equipments.*

Item.	Description.	Estimated Cost.	
		£	£
1	Track equipment of 1355.62 miles of running track, and 589.26 miles of sidings, including bonding, switch cabins, feeder connections, auxiliary power cable, and pilot and telephone lines.		5,542,400*
2	Alterations to Ways and Works:		
	a. Tunnels, bridges and structures ... ..	165,028	
	b. Telegraphs and Telephones ... ..	49,689	
	c. Signals ... ..	286,432	
	d. Track circuits ... ..	87,200	
3	Alterations to running sheds and repair shops ... ..		588,349
4	Control and maintenance offices, electrical stores depots and staff quarters.		118,000
5	Spare parts and material for locomotives, multiple-unit train equipments, track equipment and sub-stations.		48,500
6	Spare parts and material for locomotives, multiple-unit train equipments, track equipment and sub-stations.		246,000
6	Alterations to existing auxiliary power and lighting installations.		246,000
7	Contingencies, engineering expenses and interest on capital during construction.		119,074
			755,000
.	Total ... ..		£7,417,323

\* This estimate is calculated on a basis price for copper of £70 per ton, and is subject to adjustment at the rate of £13,300 for every £1 per ton by which the basis price differs from £70.

### *Estimates of Capital Expenditure.*

The estimates of capital expenditure, excluding that on locomotives and multiple-unit train equipments, are set out in detail in Table V. In the following paragraphs are given notes on the various items.

**Item 1.—Track equipment.**—Full particulars of the lines to be equipped have already been given in Table I, and we have prepared our estimates on this basis, using schedule rates taken from recent contracts for similar work of large magnitude, adapted for the conditions of manufacture and erection in this country. Adequate allowances have been made for the special work at all junctions, bridges, etc. The cost under this item includes the overhead line, structures and foundations, track bonding, the feeders from the substations, the track sectioning switch cabins and connections thereto, the auxiliary power distributing cable, and the pilot and telephone lines for power control.

**Item 2.—Alterations to Ways and Works.** The estimates set out in Table V. are those supplied to us by the Engineer.

**Item 3.—Alterations to Running Sheds and Repair Shops.**—Minor alterations would be required at the Doncaster locomotive works for dealing with electrical repairs of the locomotives during heavy overhaul, and certain running sheds would be adapted for inspection and light repairs of locomotives during the lie-over periods. Provision would have to be made for inspection and maintenance of the multiple-unit trains, and we have included an allowance in the estimate under this item for two new running sheds suitable for this class of rolling stock.

**Item 4.—Control and Maintenance Offices, Electrical Stores Depôts and Staff Quarters.**—New office buildings would be required at the headquarters of the organisation instituted to take charge of the maintenance and operation of the substations and the maintenance of the track equipment. In these buildings there would be accommodation for the control switchboard, offices for the engineers and their technical and clerical staff, mess rooms and stores. Other buildings would be required at various centres to house the track equipment and substation spares, and a provisional sum is included for staff quarters in case adequate housing accommodation is not available at all the points where the new staff will be stationed.

**Item 5.—Spare Parts and Material for Locomotives, Multiple-unit Train Equipments, Track Equipment and Substations.**—All material used for maintenance is chargeable against revenue, but the initial stocks which are provided must be included in the capital estimates. We have therefore included under this item the cost of spare parts for the electric locomotives and trains, materials such as insulators, fittings, copper and steel wire, and a number of standard structures, bonds, etc., for the maintenance of the track equipment, and spare parts for the substations, for the maintenance of which the Railway will be responsible.

**Item 6.—Alterations to Existing Auxiliary Power and Lighting Installations.**—The estimate under this item has been worked out for this Report by the Electrical Engineer.

**Item 7.—Contingencies, Engineering Expenses, and Interest on Capital during Construction.**—Under this item an allowance of £285,000 is included to provide for unforeseen expenditure, a sum of £220,000 for engineering and administration costs, and £250,000 for interest at 5 per cent. per annum on capital outlay during the construction period before each part of the complete scheme comes into beneficial use.

**Total Gross Capital Expenditure.**—The total gross capital expenditure excluding that on locomotives and multiple-unit train equipments, is £7,417,323.

### *Number and Cost of Locomotives.*

It has frequently been stated in regard to schemes for main line electrification that the cost of the electric locomotives required should not be included in the capital expenditure, on the ground that they would merely displace a number of steam locomotives of approximately equal total value which could be transferred to other sections of the Railway and utilised there to meet the demands of growing traffic, or to take the place of other locomotives due for scrapping under the normal renewal programme. It is not safe to make this assumption without investigation of the circumstances in each case. In some schemes for which such investigation has been made, the estimated credit value of the steam locomotives has been greater than that of the electric locomotives.

The number of electric locomotives to be included in an electrification scheme is sometimes estimated on the basis of the mileage which such locomotives can work per annum. It is well known, from practical experience, that electric locomotives can do, on the average, mileages of 70,000 to 100,000 per annum. Such a method of calculation is, however, too general to be satisfactory for any particular scheme. We have, therefore, arranged with the Railway that the numbers of electric locomotives of the different classes and multiple-unit trains required for actual service, should be estimated from the revised time tables, to which reference has been made above.

This has been done by the Superintendent's Department who have prepared new engine workings and calculated therefrom the number of locomotives of each class, adding thereto the number required for specials, excursion trains, and trains run in duplicate. To the number so obtained we have added the necessary allowance for spares, inspection and running repairs, and heavy repairs, such allowance being based on the experience of electrified railways already in operation. The number of shunting locomotives required for service has been agreed with the Railway, and for ballasting and departmental trains we have allowed 15 electric against 20 steam locomotives. A complete list is given in Table VI.

The prices for the locomotives of each class and of the multiple-unit equipments have been estimated by us, on the experience of recent contracts, taking into account the difference between prices for the home market and for export, and the effect on manufacturing costs of the large number required. The latter is an important consideration, especially if, as we propose, standardized designs are adopted for all locomotives in respect of traction motors, control

apparatus and auxiliary machines such as exhausters and compressors. For example, on the locomotives enumerated in Table VI., excluding the shunting locomotives, there would be 1,496 traction motors identical in all essential respects, about 8,500 unit switches, and so on. Assuming that this scheme is only one section of a general electrification of the Railways in this country, it would be possible to arrange for economical methods of manufacture of the large quantities required. It is assumed that the mechanical portions would be built in the Railway's locomotive workshops, and that the electrical equipments would be purchased. As a check on our own estimates, prices have been obtained from electrical manufacturers, and we think the estimates can be accepted as reliable.

The list of steam locomotives released in consequence of electrification is given in Table VII., together with the total amount to be provided for their renewal in accordance with the Chief Accountant's calculations, namely, £3,998,298. Comparing this figure with the total in Table VI. for electric locomotives, viz., £5,507,090, and assuming that it is correct to regard the renewal value of steam locomotives as the credit value (taking into account the fact that steam locomotives of an average age of between 21 and 22 years would be replaced by new electric locomotives), there would be a balance of £1,508,792 Capital Expenditure chargeable against electrification.

TABLE VI.  
NUMBER AND COST OF ELECTRIC LOCOMOTIVES AND MULTIPLE UNIT TRAIN EQUIPMENTS.

Item.	Number.	Description.	Rate.	Total.
			£	£
1	35	Passenger locomotives ... ..	16,250	568,750
2	258	Motor coach equipments ... .. (i)	5,130	1,323,540
3	516	Trailer coach equipments... .. (ii)	420	216,720
4	178	Class A goods locomotives ... ..	7,860	1,399,080
5	32	Class B do. do. ... ..	11,570	370,240
6	28	Class B1 mixed traffic locomotives ... ..	11,490	321,720
7	14	Class B1 do do. do. with boilers.	12,000	168,000
8	75	Shunting locomotives for goods yards ... ..	7,080	531,000
9	63	do. do. for passenger train shunting.	7,780	490,140
10	15	Class A locomotives for ballasting and departmental trains.	7,860	117,900
		Total ... ..		£5,507,900

NOTE.—(i) This price includes the extra cost of providing motor bogies instead of ordinary carriage bogies, and wiring and fitting coaches for electric heaters.

(ii) This price includes the cost of alterations to the coach bodies, and wiring and fitting coaches for electric heaters.

TABLE VII.  
NUMBER, TYPE, AGE AND ESTIMATED NETT RENEWAL VALUE OF STEAM LOCOMOTIVES DISPLACED BY  
ELECTRIFICATION.

Number.	Type.	Average Age.	Estimated Nett Renewal Value.
35	4-6-2 Tender	4.96 years	£3,998,298
23	4-6-0 "	20.23 "	
80	4-4-2 "	23.66 "	
96	4-4-0 "	27.28 "	
2	2-8-2 "	4.50 "	
139	2-8-0 "	11.98 "	
82	2-6-0 "	8.54 "	
27	0-8-0 "	23.03 "	
223	0-6-0 "	22.82 "	
1	Steam Rail Motor	1.08 "	
3	4-8-0 Tank	11.50 "	
2	4-6-2 "	15.37 "	
18	4-4-2 "	22.18 "	
2	2-6-4 "	13.80 "	
9	0-8-2 "	24.08 "	
1	0-6-4 "	24.83 "	
27	0-6-2 "	12.46 "	
159	0-6-0 "	31.34 "	
2	0-4-4 "	29.41 "	
925			

An alternative method of consideration is to base the estimate of credit on the annual expenditure by the Company on complete renewals of locomotives. The number renewed and the cost of such renewals during recent years are as follows:—

Year.	1925.	1926.	1927.	1928.	1929.
Number renewed ... ..	148	115	128	160	110
	£	£	£	£	£
Expenditure on renewals, including proportion of supervision and shop expenses.	678,450	446,849	406,677	592,979	448,880

On the average during the years 1925 to 1929 inclusive, 132 locomotives per annum have been renewed at a cost of £514,767, this number representing 1.8 per cent. of the total stock of about 7,400. It may be assumed that the electric locomotives will begin to displace steam locomotives two years after the start of construction, and that all the 925 steam locomotives will have been displaced three years later. During these three years there will be an expenditure of £1,835,697 per annum on electric locomotives and nothing on renewals of steam locomotives. Failing electrification the usual expenditure on renewals, viz., £514,767 per annum, would continue. Assuming that obsolescence or scrapping of steam locomotives in service continues at the rate of 132 per annum, there would be no need to begin steam locomotives renewals again for 7 years.

Allowing compound interest at 5 per cent. the saving of this annual amount for 7 years is equivalent to a saving of £1,094,000 per annum for 3 years. The net expenditure on locomotives is, therefore, £741,697 per annum (i.e., £1,835,697 minus £1,094,000) for 3 years, i.e., a total of £2,225,090 chargeable against electrification.

It will be noted that the average rate of renewal of steam locomotives, viz., 1.8 per cent. per annum is a good deal less than the rate based on the accepted life of 33½ years, i.e., 3 per cent. If the latter figure were worked to, the number replaced annually would be about 222, and assuming the same average price per locomotive the annual expenditure would be £866,000. At this rate renewals would begin again after 4.16 years, and on this basis the amount chargeable against electrification would be about £2,000,000.

Opinions may differ as to which of these methods of estimation should be adopted, but we think that taking all the circumstances into account it would be reasonable to debit the electrification scheme with a capital expenditure of £2,000,000 in respect of the electric locomotives and multiple-unit train equipments.

#### *Credits for Released Assets other than Steam Locomotives.*

Electrification will result in the release of certain buildings, plant and machinery, and other assets now required in connection with steam operation, and the Chief Accountant has supplied us with their values. Some items would be wholly dispensed with, as, for example, stocks of coal for locomotive purposes, but others, e.g., locomotive workshops and running sheds, would still be utilised, though to a smaller extent, under electric conditions. In such cases we have made the necessary adjustments to the figures, and the first column of Table VIII. shows the value of the portion of each item which would be released, after allowing for the requirements of the electric services.

The items may be divided into three groups—(a) those which are realisable to their full value, (b) those on which some proportion of their book value or renewal value is recoverable, and (c) those for which no practicable amount would be realised. The total of group (a) is £515,000, and this amount must be credited in full. The total of group (b) is £329,000. We have considered with the Chief Accountant what credit value should be taken for each of the items in this group, and the figures are given in the second column of Table VIII., the total being £256,000. The total of group (c) is £287,000, but we see no reason to assign any credit value to any of the items in this group.

The figures include a credit for 1,296 locomotive coal wagons which would be released for use in other services. There would also be some reduction in the number of companies' and traders' wagons due to the saving in running time which amounts to 4,900,000 wagon hours per annum. It is, however, difficult to make an actual estimate of this reduction, and no credit has, therefore, been taken on this account.

#### *Net Capital Outlay.*

Adding to the gross capital outlay as given in Table V., the amount chargeable for locomotives, and deducting the credits as set out in Table VIII., the net capital outlay is obtained. The figures are contained in Table IX., which shows that the net total is £8,646,323.

#### *Working Expenses.*

The working expenses with steam operation are set out in the first column of Table X., and are in accordance with information supplied to us by the Chief Accountant. The figures are based on the actual costs for the year 1929, with an increase of 2½ per cent. on the wages to correspond with the rates now in force. The costs under Item 1, Locomotive fuel, are calculated on the present price of coal and are subject to variation as the price varies; for each shilling per ton rise or fall the total under this item would be increased or decreased by £30,012. The various items of working expenses with electric operation are set out in the second column of the same Table. The following notes will explain how these estimates have been prepared.

Item 1.—Electric Power.—The cost of power is the largest item in the working expenses with electric operation, and it is therefore important that the figures should be accurately estimated.

**TABLE VIII.**  
**LIST AND VALUES OF ASSETS DISPLACED BY ELECTRIFICATION.**

Item.	Description.	Book Value or Replacement Value.	Credit Value.
GROUP (a)	95 coaches released by acceleration of service ... ..	£ 85,000	£ 85,000
	1,298 locomotive coal wagons ... ..	168,000	168,000
	Locomotive spare parts ... ..	200,000	200,000
	Coal stock ... ..	62,000	62,000
		515,000	515,000
GROUP (b)	Surplus plant and machinery in locomotive workshops ...	95,000	85,000
	Plant and machinery in surplus running sheds and pump-houses.	48,000	43,000
	Surplus permanent way at locomotive workshops ... ..	4,000	1,000
	Permanent way at surplus running sheds ... ..	41,000	7,000
	Coaling appliances ... ..	20,000	18,000
	Train lighting sets ... ..	113,000	102,000
	321,000	256,000	
GROUP (c)	Land at locomotive workshops (portion) and surplus running sheds.	25,000	—
	Locomotive workshop buildings (portion) ... ..	49,000	—
	Surplus running shed buildings ... ..	124,000	—
	Surplus pumphouses, water-tanks, water mains, etc. ...	77,000	—
	Turntables ... ..	12,000	—
		287,000	—
	Total Credit ...	—	£771,000

**TABLE IX.**  
**NET CAPITAL OUTLAY.**

Gross capital outlay (excluding locomotives and multiple unit train equipments), Table V.	£ 7,417,323
Charge for locomotives and train equipments ... ..	2,000,000
	£9,417,323
Less credit Table VIII ... ..	771,000
Net capital outlay ... ..	£8,646,323

The principal basis of the calculation is the assumed tractive resistance for each class of rolling stock, locomotives, passenger coaches, and wagons with various tares and loads, under the different conditions of speed appropriate to each class. We have made a special study of this subject in the last 25 years, during which we have been connected with various railway electrification schemes, and have collected a large amount of information, partly from special tests and operating experience on these railways and partly from published and unpublished records of experience on other railways. We are confident, therefore, that the assumptions we have made are substantially correct. On the basis of these figures, as applied to the statistics of engine miles and trailing ton miles, we have calculated the annual energy consumption, and have added allowances for unbooked traffic delays, for bad weather conditions and for heating and lighting the passenger trains. The costs in the Table are derived from these calculations by multiplying the number of units by the price per unit referred to above and, as already mentioned, are subject to variation in the price of coal, a rise or fall of one shilling per ton corresponding to an increase or decrease in the total for this item of £10,568.

It will be noted that the cost of power for passenger and goods trains is higher than the cost of locomotive fuel, but that for shunting and departmental traffic there is a considerable saving by electrification. This difference is partly accounted for by the large reduction in shed shunting, but mainly by the economy of operation of electric shunting engines in goods yards and passenger sidings as compared with the low efficiency under such conditions of steam locomotives. There are, of course, no complete records of the actual work, in ton mileages, carried out by shunting locomotives; and in order that there should be no room for criticism of the calculated cost of electric energy for this work a special investigation was made at our request as to the average load moved, the average length of shunt, and the average speed, of several engines in yards selected as representative of all the goods yards on the system. The results of this investigation have been used as the basis for the calculation of ton mileage for goods shunting by shunting engines.

**TABLE X.**  
**COMPARATIVE WORKING EXPENSES, STEAM AND ELECTRIC.**

Item.	—	Steam.		Electric.	
1	Locomotive fuel (including haulage and handling) or electric power:—	£	£	£	£
	Passenger traffic ... ..	171,583		261,000	
	Goods traffic... ..	247,918		283,330	
	Shunting and departmental traffic ...	105,368		42,900	
			524,869		586,620
2	Water for locomotive purposes:—				
	Passenger traffic ... ..	12,200		300	
	Goods traffic... ..	17,600		—	
	Shunting and departmental traffic ...	7,308		—	
			37,108		300
3	Lubricants for locomotives:—				
	Passenger traffic ... ..	4,223		1,770	
	Goods traffic... ..	4,565		1,580	
	Shunting and departmental traffic ...	2,121		530	
			10,909		3,880
4	Locomotive stores, clothing and miscellaneous:—				
	Passenger traffic ... ..	16,321		8,740	
	Goods traffic... ..	17,334		9,270	
	Shunting and departmental traffic ...	10,021		5,450	
			43,676		23,460
5	Drivers' and Firemen's wages and allowances, including relief and shed drivers and holidays:—				
	Passenger traffic ... ..	149,950		84,406	
	Goods traffic... ..	305,894		125,089	
	Shunting and departmental traffic ...	215,821		108,969	
			671,665		318,464
6	Locomotive cleaning, boiler washing shed and yard services:—				
	Passenger traffic ... ..	41,574		11,570	
	Goods traffic... ..	44,158		17,800	
	Shunting and departmental traffic ...	25,488		10,200	
			111,220		39,570
7	Supervision:—				
	Passenger traffic ... ..	10,786		7,000	
	Goods traffic... ..	11,119		7,200	
	Shunting and departmental traffic ...	6,490		4,200	
			28,395		18,400
8	Locomotive repairs:—				
	Passenger traffic ... ..	136,076		77,480	
	Goods traffic... ..	209,597		75,670	
	Shunting and departmental traffic ...	93,020		34,270	
			438,693		187,420
9	Maintenance of engine sheds, watering appliances, etc.:—				
	Passenger traffic ... ..	5,442		2,170	
	Goods traffic... ..	5,794		2,310	
	Shunting and departmental traffic ...	3,296		1,320	
			14,532		5,800
10	Maintenance of train lighting sets... ..		17,028		—
11	Wages of guards, including allowances:—				
	Passenger traffic ... ..	40,201		34,722	
	Goods traffic... ..	128,944		105,670	
			169,145		140,392
12	National Insurance, workmen's compensation, superannuation and pensions.		32,218		14,900
13	Maintenance and operation of sub-stations		—		35,800
14	Maintenance of track equipment ... ..		—		97,880
15	Auxiliary power supplies and maintenance:—				
	Electric power ... ..	53,196			
	Gas ... ..	42,676			
	Oil ... ..	5,115			
	Hydraulic ... ..	2,500			
			103,487		57,994
16	Depreciation:—				
	Locomotives... ..	55,965		72,750	
	Track equipment ... ..	—		31,150	
			55,965		103,900
	Total ... ..		£2,258,910		£1,634,280
	Difference in favour of electrification ... ..				£624,630

Item 2.—Water for Locomotive Purposes.—The expenditure on water for locomotive purposes appearing in the steam working costs includes the cost of water purchased, and the working costs and repairs and renewals of the Railway-owned pumping stations and plant. It also includes the necessary expenditure on water cranes and columns. The figures relate to water for locomotive purposes only, and do not include any supplies for carriage washing and other purposes. The only water required for locomotive purposes with electric working will be that for heating trains. This will be a relatively small quantity, and could be taken from the same sources as that for carriage washing, etc. Practically the whole of the expenditure on water for locomotive purposes would thus be eliminated.

Item 3.—Lubricants.—The costs under this item have been estimated from experience with electric locomotives of similar designs, and multiple-unit trains, on a number of railways that have been in operation for some years.

Item 4.—Locomotive Stores, Clothing and Miscellaneous.—The locomotive stores are those required for cleaning locomotives, boiler washing, firelighting, and tube cleaning, engine lamps, tools and fittings and sand. There will be reductions in respect of cleaning material, lamps, tools and fittings, and boiler washing, etc., will be eliminated. With a reduced personnel the expenditure on clothing should be correspondingly reduced.

The item "miscellaneous" includes lighting of running sheds on which there should be a substantial reduction as a number of the existing sheds would no longer be used, and other general charges which would not be materially altered.

Item 5.—Drivers' and Firemen's Wages.—These costs have been estimated by the Superintendent in consultation with the Chief Accountant from the revised time tables showing electric working. Allowances have been included based on actual results with steam working adapted to electric conditions, for overtime, relief and shed drivers, and holidays. With the elimination of the coal-fired boilers, there would no longer be any necessity to provide two men on each locomotive; the equipment requires no attention during running, and one man is sufficient for the duties of driving. It is already customary to put one man in control of multiple-unit electric trains, and on electrified main lines on the Continent the principle is being extended to all trains excepting the long distance passenger expresses. To safeguard the train in the event of the motorman or driver being taken ill, a "dead man handle" would be provided, which would automatically cut off the power and apply the brakes. This device is available in different designs suitable for suburban multiple-unit trains, and for electric locomotives. The estimates have been worked out on the assumption that there would be a single driver on each multiple-unit train, goods train and shunting locomotive, but that there would be two men on each locomotive-hauled passenger train, though the second man need not necessarily be on the locomotive the whole of his time.

Item 6.—Locomotive Cleaning, Boiler Washing, Shed and Yard Services.—We have worked out the estimate for wages for cleaning electric locomotives which will be substantially less than the corresponding cost for steam locomotives, partly on account of the reduced number (the multiple-unit train requiring nothing special apart from the ordinary carriage cleaning), and partly due to the elimination of coal and steam. The boiler washing will be eliminated. The shed and yard services include wages in connection with engine lamps and tools, sanding expenses, stores issuing, regulation of enginemen's duties, and general labour, on all of which there will be some, though not considerable, reduction.

Item 7.—Supervision.—Under this item are included the wages and expenses at locomotive running sheds of inspectors, foremen, clerks and time-keepers. With a reduction in the number of sheds in use and in the number of drivers and firemen, there will be a proportionate saving under this head.

Item 8.—Locomotive Repairs.—There is a considerable body of information as to the cost of electric locomotive repairs, a good deal of which has not been published, but has been given to us privately. On the basis of this information we have made a careful estimate for the present scheme, and have included under this item materials, labour, supervision, shop expenses and upkeep of plant, for running repairs and for periodical heavy overhaul. Provision has been made for the renewal of parts subject to wear or deterioration throughout an assumed life of 33½ years.

Item 9.—Maintenance of Engine Sheds, Watering Appliances, etc.—Under this item are included the cost of wages and material for the maintenance of the civil engineering portion of engine sheds, workshops, turntables and other locomotive facilities. Due to the reduction in the number of locomotives, and the smaller amount of repair work necessary with electric working, a number of sheds will be dispensed with, and some part of the workshops will no longer be required. The turntables will no longer be necessary, as the electric locomotives can be driven equally well in either direction. Taking these considerations into account, we have made an estimate on the basis of the cost of steam working of the figure for electric working.

Item 10.—Maintenance of Train Lighting Sets.—With the conversion of a large number of passenger coaches for operation in multiple-unit trains, the expenditure on the maintenance of the dynamos and accumulators on these coaches would no longer be incurred.

Item 11.—Wages of Guards.—Due to the speeding up of the less important passenger trains and the goods trains, there would be a saving in respect of guards' wages. The costs under electric working have been estimated for us by the Superintendent in consultation with the Chief Accountant, and are given in the Table as received.

Item 12.—National Insurance, Workmen's Compensation, Superannuation and Pensions.—The expenditure under this item is in connection with drivers and firemen, all staff employed on the maintenance of engines, whether in the sheds or in the workshops, and guards. We have based the estimate for electric working on the expenditure for steam working, taking into account the reduction in the number of men required.

Item 13.—Maintenance and Operation of Substations.—We have worked out the complete organisation for the maintenance and operation of the substations, and have estimated the supervision and labour costs from information as to standard rates of pay supplied to us. We have also included a liberal estimate of the cost of materials required for maintenance purposes.

Item 14.—Maintenance of Track Equipment.—Similarly for the track equipment we have worked out a suitable organisation based on experience gathered from a number of electrified railways, and have calculated therefrom the cost of supervision and labour. The amount of material required for maintenance is normally quite small, but we have thought it prudent to make allowance for the complete renewal of all the contact wires every 20 years. These are the only wires subject to wear and tear.

Item 15.—Auxiliary Power Supplies.—Information has been compiled for us as to the power required for auxiliary purposes, including the installations (railway station and yard lighting, cranes, capstans, etc.), where electricity is already employed, and for others where gas, oil and hydraulic power are now used, and which would be converted. The maintenance costs under this item have been estimated for us by the Electrical Engineer's Department.

Item 16.—Depreciation.—We have calculated the annual amounts to be set aside for depreciation of the track equipment and electric locomotives on a sinking fund basis, taking compound interest at 4 per cent. per annum, as assumed by the Chief Accountant in preparing the figures for steam working.

For the electric locomotives and multiple-unit train equipments we have taken a life of 33½ years (the same as assumed for steam locomotives), and this requires an annual payment, on the basis mentioned above, of 1½ per cent. on the first cost, less scrap value.

For the line equipment, consisting mainly of copper wires, steel structures, copper rail bonds, and a small amount of insulated cable, we have assumed a life of 50 years, i.e., 0.65 per cent. on the first cost less scrap value. For the track sectioning switches we have taken a life of 33½ years, i.e., 1½ per cent. on the first cost, the scrap value of this item being negligible.

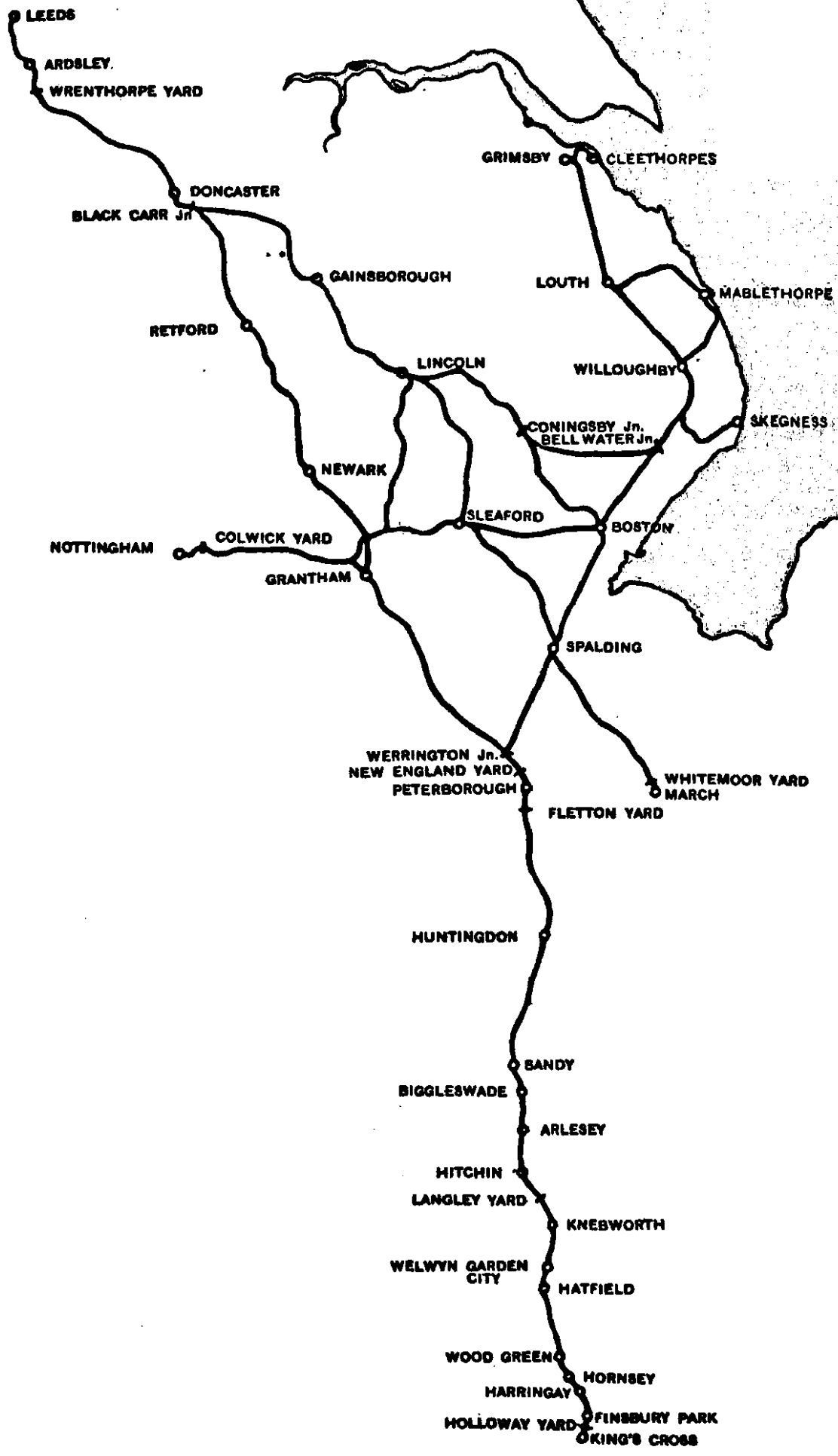
*Summary of Comparative Working Expenses and the Financial Result.*

It will be seen from Table X. that the total of the comparable items of working expenses with steam operation is £2,258,910, and with electric working £1,634,280. The annual saving due to electrification is therefore £624,630. This is equal to 7.22 per cent. on the net capital expenditure of £8,646,323, and is available for payment of interest and any additional local rates for which the Railway may be liable in respect of the substations and the track equipment. For any variation in the price of coal from present rates, the annual saving will be affected to the extent of an increase or decrease of £19,454 for each shilling increase or decrease in the price per ton, equivalent to 0.225 per cent. on the net capital expenditure.

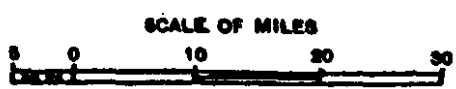
In carrying out this investigation we have kept throughout in close touch with the officers of the Railway, who, at the expense of much hard work, have prepared all necessary statistics of traffic, estimates of alterations to ways and works, steam working costs and valuation of assets. They have also drawn up revised time tables for electric working, have calculated for us on the basis of this revision two important items of the electric working costs, and have advised us as to the number of electric locomotives of different classes necessary for dealing with the traffic. We wish to express our appreciation of the way in which this work has been done.

MERZ AND McLELLAN.





**LONDON & N.E. RAILWAY.  
MAP OF ROUTES CONSIDERED IN THE REPORT**



## APPENDIX V.

REPORT BY MESSRS. MERZ AND McLELLAN ON THE ELECTRIFICATION OF A PORTION OF THE  
LONDON MIDLAND AND SCOTTISH RAILWAY.

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## PLATES ILLUSTRATING THE REPORT.

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PLATE II.—Typical through passenger engine runs.

September, 1930.

THE SECRETARY,  
RAILWAY ELECTRIFICATION COMMITTEE.

SIR,

We beg to submit herewith our Report on the electrification of a portion of the London, Midland and Scottish Railway, which we have investigated in collaboration with the railway officials in accordance with the Committee's instructions. The scheme, as suggested by the Company's representatives and approved by the Committee, includes the main line from Crewe to Carlisle, the line from Weaver Junction to Lime Street, Liverpool, and certain loops and minor branches connected with the main line. This section is one with certain rather heavy gradients and has a traffic density above the average—both factors usually favourable to electrification.

The Report gives full particulars of the traffic to be dealt with, the sub-division between steam and electric working of the traffic on the electrified sections, the proposed accelerations for all classes of traffic, estimates of gross and nett capital outlay on electrification, comparative estimates of steam and electrical operation and the financial result based on these figures.

Summarised very briefly, the figures are as follows:—

Total route mileage, about ... ..	193
Total single track mileage, including yards and sidings, about ... ..	843
Trailing ton miles, to be worked electrically, per annum, about ... ..	2,225,000,000
Engine miles, electric, per annum, about ... ..	7,947,000
Nett capital outlay ... ..	£5,123,370
Saving in working expenses ... ..	£127,766

representing 2.5 per cent. on the nett capital outlay.

From this saving of £127,766 per annum, must be deducted the increase, if any, in the local rates payable by the Railway Company in respect of the track equipment and the substations, which in the present circumstances, we have not attempted to estimate.

It will be seen from the foregoing figures that the saving resulting from electrification under the conditions laid down is not sufficient to pay the interest charges on the nett capital outlay. This result, in view of the conditions mentioned in the first paragraph, calls for some explanation. We have, therefore, in accordance with your wishes, made a further analysis of the conditions of operation, the results of which are set forth in our Report. The more important are as follows:—

(1) Although in other electrification schemes electric shunting has proved profitable, in the present case it was decided, initially, in order to limit the scope of the investigation, not to include any arrangements for electric shunting in the main goods yards, and to equip only the entrances to the sidings, so as to enable the train engines to haul their trains into the yards. The mileage of track to be so equipped, however, proved to be much greater than was expected, and the greater part of the sidings had to be included.

(2) The electric locomotives under this scheme would work an annual mileage of about half as much as electric locomotives can do, and actually are doing to-day on other systems. This is mainly due to:—

(a) The comparatively small size of the scheme.

(b) The amount of dual working (i.e., running part of a train journey with steam and part with electric locomotives).

Thus, while the distance from Crewe to Carlisle is 141 miles, the average length of electric locomotive run for booked passenger trains is only 43 miles, and for goods trains 42 miles. The average annual mileage is 35,000 against a possible 70,000 or 80,000. Some of the locomotives, moreover, would lie over between turns for 15 or 16 hours per day, thus increasing both the number required and the cost of the crews. The railway officers, as the result of a special investigation, find that the steam engines now running, wholly or partially, on the sections to be electrified, cover a total of 15,800,000 miles per annum, of which about 5,800,000 are on lines outside the scheme. To do this mileage 614 steam engines are now used, of which 379 would have to be retained after electrification, and 220 electric locomotives added. Thus, while electrification would eliminate 53 per cent. of the steam locomotive mileage, only 38 per cent. of the existing engines would be released, and the total number of locomotives would be reduced by only 2½ per cent. If the electrification scheme were more extensive, and adjacent sections were included, the locomotives would be used to better effect.

We trust that the Committee will find in this Report the information that they require, but we are at their disposal to elucidate any points on which they would like further information.

Yours faithfully,

MERZ AND McLELLAN.

## LONDON, MIDLAND AND SCOTTISH RAILWAY ELECTRIFICATION.

This report deals with an investigation into a scheme of electrification for a portion of the London, Midland and Scottish Railway. The sections which are included in the scheme are shewn on the map in Plate I accompanying this report and comprise the line between Crewe and Carlisle (including the Winwick-Golbourn and Whelley loops), the line from Weaver Junction (16 miles north of Crewe) to Lime Street, Liverpool, and the branch lines to Windermere, Over and Wharton, Garston and Morecambe (N.W.R.). It has also been found necessary in order to provide for inter-running to include in the scheme the line from Lancaster to Morecambe and Heysham. This is at present partly worked electrically, on a single phase alternating current system, and would be re-equipped to conform with the other sections.

The selection of these lines was made with three considerations in view:—

- (1) It was desired, principally, that the scheme should consist of main lines carrying heavy traffic in an area mainly industrial.
- (2) It was considered advantageous to include lines with heavy gradients on which substantial economies might be expected due to the special features of electrical operation.
- (3) It was to be assumed that electric working was limited to the lines considered, i.e., that the scheme was not to be regarded as part of a general electrification of the railways in this country.

In regard to these considerations, it should be remarked that, although the traffic on the sections selected is fairly heavy, the ton mileage per mile of route is a good deal less than on some other sections of the Railways in this country. The gradients on the line are comparatively severe, there being a stretch of 4 miles of 1 in 75 between Tebay and Shap Summit; there are also long stretches of 1 in 106, 1 in 125, and other gradients steeper than 1 in 200 on all parts of the line, the average over the 31 miles between Shap Summit and Carlisle being 1 in 195.

In regard to the third consideration, it was thought that on the sections selected only a small proportion of the traffic would still have to be worked by steam, and that there would be little alteration to existing working arrangements by reason of the change over from steam to electric locomotives at the terminal points. As the result of investigation, it has been found that this anticipation has only partly been realised, as will be seen from the particulars of traffic in Tables II and III. The change of locomotive at the terminal points has its effect on the extent to which the electric locomotives can be fully employed, and apart from this there are a number of intermediate points where a similar change is necessary if an excessive amount of steam working on the electrified lines is to be avoided.

In order to limit the scope of the investigation, it was decided initially not to include in the electrification scheme any arrangements for shunting in the main goods yards by electric shunting locomotives, and to equip only the entrances to the various sidings so as to enable train engines to haul their trains into the yards and leave them there to be broken up or marshalled by existing steam shunting locomotives. The Railway Officers indicated to us which tracks in the shunting yards and stations should be electrically equipped. The mileage of track to be equipped is much greater than we anticipated, in fact, the greater part of all the sidings at the terminal and principal intermediate stations (except in the Liverpool area) would have to be included. As an example of this it may be mentioned that at Crewe, which is regarded only as a terminal point where electric locomotives may pick up or deliver their trains, and run to and from the engine shed, track equipment is provided for 73 miles of running lines and sidings. The result of this decision is, therefore, that, although the goods yards are to a considerable extent equipped for electric working, advantage has not been taken of this to realise the economies resulting from the use of electric shunting locomotives.

The route and single track mileages are given in Table I.

TABLE I.  
ROUTE AND SINGLE TRACK MILEAGE.

ROUTE MILEAGES.		
(1) Crewe—Carlisle	...	141.0
(2) Winwick—Golbourn Loop	...	3.3
(3) Whelley Loop	...	6.5
(4) Over and Wharton Branch	...	1.0
(5) Morecambe Branch (formerly L. & N.W.R.)	...	1.7
(6) Heysham—Morecambe—Lancaster Branch	...	8.9
(7) Windermere Branch	...	10.3
(8) Weaver Junction—Liverpool	...	19.4
(9) Garston Branch	...	1.3
Total	...	193.4
SINGLE TRACK MILEAGES.		
Running lines and sidings in running lines	...	646.8
Traffic sidings	...	191.1
Traders' sidings	...	5.4
Total	...	843.3

**TABLE II.**  
**TRAFFIC STATISTICS.**  
*Summary of Trailing Ton Mileages.*

	Present.	Proposed.	
	Steam.	Steam.	Electric.
Passenger ... ..	1,140,970,956*	212,618,314	928,352,642*
Freight ... ..	1,419,141,678	169,365,032	1,243,776,646
Departmental ... ..	51,395,760	11,165,940	40,229,820
Shunting by train engines ... ..	14,512,616	1,980,215	12,552,401
<b>Total ... ..</b>	<b>2,620,021,010*</b>	<b>395,109,501</b>	<b>2,224,911,509*</b>

\* Includes 8,507,576 ton miles on the Heysham-Morecambe line worked by electricity.

*Traffic Statistics.*

Particulars of the traffic on the sections to be electrified have been taken out from the records and careful investigation has been made as to which trains running over the equipped lines should be electrically hauled and which should continue to be worked by steam. The principle followed in making this division is, in general, that trains to or from points off the electrified section which only run for a short distance on the electrified lines would continue to be worked by steam. All other trains would be worked electrically.

A summary of the trailing ton mileages is given in Table II., in the first column of which are the total ton mileages for the different classes of traffic which are worked on the lines in question at present. In Columns 2 and 3 these figures are sub-divided according to the proposed method of working, and it will be seen that, for the passenger traffic, nearly 20 per cent. of the trailing ton miles would continue to be worked by steam, and for freight traffic about 12 per cent.

*Traffic Working.*

After consultation with the officers of the Railway, it was decided that passenger traffic conditions were not suitable for the use of multiple-unit trains (apart from the existing electric service on the Heysham-Morecambe-Lancaster Branch), and that all passenger trains to be worked electrically should be hauled by electric locomotives. For the goods traffic there is no question in this investigation of any alternative method of working than by locomotive. Therefore, the electrification scheme in this instance consists in the substitution for steam of electric locomotives of types suitable for the working conditions of the various classes of traffic.

Advantage has been taken of the possibility of providing locomotives of greater power than the steam locomotives in general use, to speed up all classes of traffic with electric working. This is effected by raising the average speed due to faster running up the gradients, but without any increase in the maximum speeds. The limiting speeds for the various classes of train (see notes to Table III.) have been taken as follows:—

	<i>Miles per Hour.</i>
Passenger trains ... ..	75
Fitted freight No. 1 ... ..	55
Fitted freight No. 2 ... ..	50
Express freight ... ..	40
Through freight ... ..	35
Empty wagon ... ..	30
Mineral ... ..	25

A comparison of the present net running times between Crewe and Carlisle with those proposed under the new conditions is given in Table III. Revised time tables have been prepared for the traffic on the electrified sections, which take into account all the traffic conditions. They show that in some instances the actual saving of time on the journey is much greater than the saving calculated from the present and proposed standard net timings, while in other instances it is less. Examples of the actual saving are given in the last column of Table III, which must be compared with the last column but one. These time tables have been used to determine the number of electric locomotives required, and to calculate the wages of the electric locomotive crews (as given in Table VIII).

TABLE III.  
COMPARISON OF PRESENT STEAM AND PROPOSED NET RUNNING TIMES.

Class of Train.	Present Standard Timing.	Proposed Standard Timing.	Proposed Acceleration.	Actual Acceleration for Sample Trains.
<b>Crewe to Carlisle.</b>	hrs. mins.	hrs. mins.	mins.	mins.
Passenger limited load ... .. (1)	2 44	2 23	21	{ 29½, 17, 21 25. 27, 25, 22
Passenger full load ... .. (1)	2 58	2 23	35	39½, 28
Fitted freight No. 1. ... .. (2)	3 48	3 1	47	—
Fitted freight No. 2 ... .. (3)	3 56	3 12	44	56, 68
Express freight ✕ ... .. (4)	4 41	4 16	25	155, 54, 139, 96
Express freight ... .. (4)	5 10	4 28	42	33, 80
Through freight or empty wagon (5)	5 56	4 33	83	33
Mineral ... .. (6)	6 43	5 55	48	—
<b>Carlisle to Crewe.</b>				
Passenger limited load ... .. (1)	2 55	2 20	35	38, 41, 36, 34
Passenger full load ... .. (1)	3 8	2 20	48	43, 41, 44
Fitted freight No. 1 ... .. (2)	3 55	3 2	53	26
Fitted freight No. 2 ... .. (3)	4 0	3 11	49	105
Express freight ✕ ... .. (4)	4 42	4 21	21	105, 35
Express freight ... .. (4)	5 18	4 30	48	—
Through freight or empty wagon (5)	6 2	4 37	85	120, 75, -8
Mineral ... .. (6)	6 44	5 54	50	—

(1) Passenger trains "limited load" include most of the long distance express trains. The "full load" trains are 10 to 15 per cent. heavier and somewhat slower.

(2) Fitted freight trains No. 1 must be piped throughout for automatic brakes, and the brakes must be operative on not less than half the wagons and the brake van. Vehicles must have close couplings and oil axle boxes.

(3) Fitted freight trains No. 2 must contain at least 50 per cent. of vehicles on which the automatic brakes are operative. The remainder of the train may consist of loose coupled unpiped vehicles, but the train must have oil axle boxes throughout.

(4) Express freight trains consist of general merchandise, and have no automatic brake except those marked ✕, which have 4 fitted vehicles next the engine.

(5) Through freight trains contain general merchandise, and have no automatic brake. Empty wagon trains need have no automatic brakes.

(6) Trains consisting of coal, iron, stone, sand, grain, potatoes and similar loads are classed as mineral trains. They have no automatic brakes.

The engine mileages, steam and electric, for the different classes of traffic, are set out in detail in Table IV. It will be noted that the total engine mileage on the electrified sections is about 6 per cent. less than under existing conditions. This difference is due to a reduction in the assisting required mileage and consequently in the light mileage. With the electric locomotives proposed, there should be no assisting at all for passenger trains, and for goods traffic only such banking as is called for by the regulations, which lay down that under certain circumstances there must be an engine at the rear of the train. It will be seen also that there is no difference in the respective figures of train mileage, neither coaching nor goods. In regard to the coaching traffic this calls for no comment, but it might be expected that something could be done in the way of increasing the average load of the goods trains, which is 421 tons, and thereby reducing the number of trains and consequently the cost of working. This matter has been carefully considered with the Railway Officers, who have pointed out after an investigation into a typical day's working that practically all trains are limited in weight, not by engine power, but by other considerations which are not affected by electrification. For example, many trains vary in weight during their journey by picking up and dropping numbers of wagons at intermediate points, so that although during part of the journey the weight of the train may be as high as the drawgear will permit, the average weight is comparatively small. It was decided therefore that no attempt should be made to revise the basis of goods train working except, as already mentioned, in respect of the speed of travel.

#### *Electric Locomotives.*

On a careful examination of the requirements of the passenger traffic and the train loads, we have come to the conclusion that two classes of electric passenger locomotive would be required. For the principal expresses between Crewe and Carlisle which may have a tare weight of 495 tons we should propose a locomotive with four driving axles and a leading and trailing truck, weighing about 110 to 115 tons. This would be equipped with motors having a total capacity of 2,400 horse power, and would be capable of hauling the heaviest trains up the 1 in 75 gradient without assistance, and of maintaining a steady speed of 70 miles per hour on the level. For lighter trains up to 380 tons tare weight a less powerful, and less expensive, locomotive of 1,800 horse power capacity would be suitable. This would be capable of the same performance with the lighter trains as the 2,400 horse power locomotive with the heaviest trains. It would also be used for fitted freight trains, and both classes of passenger locomotive would be used as convenient for specials.

As already mentioned, the weights of goods trains vary between wide limits. From a careful study of the records we should propose that except for a few small locomotives for banking and hauling departmental trains, one class of goods locomotive should be provided for all trains

except fitted freight No. 1 and No. 2. The small locomotive, referred to below as Class A would be of the four-axle double bogie type, with a weight of 72 tons and a capacity of 1,200 horse power. The goods locomotive, referred to as Class B, would also be of the double bogie type, but each bogie would have three driving axles and 3-360 horse power motors, making an aggregate capacity of 2,100 horse power. The total weight would be 108 tons.

#### *Electrical System and Track Equipment.*

We have assumed that the recommendation of the Ministry of Transport Committee on Electrification would be adopted and that all lines would be equipped with overhead wires for distribution to the trains of direct current at 1500 volts, and that the running rails would be used for the return circuit.

TABLE IV.  
LOCOMOTIVE WORKING.  
*Summary of Engine Miles.*

	Existing Conditions.	Future Conditions.	
	Steam.	Steam.	Electric.
<b>COACHING.</b>			
Train ... ..	5,174,037*	976,174	4,197,863*
Shunting by train engines ... ..	19,422	3,327	16,095
Light ... ..	311,636†	60,102†	87,187†
Assisting required ... ..	124,702	22,603	—
Assisting not required ... ..	126,620	24,443	121,906
Total ... ..	5,756,417*	1,086,649	4,423,141*
<b>GOODS.</b>			
Train ... ..	3,334,688	376,654	2,958,034
Shunting by train engines ... ..	201,032	26,631	174,401
Light ... ..	431,678†	48,758†	165,838†
Assisting required ... ..	167,856	14,380	55,000
Assisting not required ... ..	64,090	7,239	51,894
Total ... ..	4,199,344	473,662	3,405,167
BALLASTING ... ..	130,198	27,994	102,204
OTHER DEPARTMENTAL ... ..	20,966	4,847	16,119
Total ... ..	10,106,926*	1,593,152	7,946,631*

\* Includes 116,511 miles on the Heysham—Morecambe—Lancaster Branch worked by electricity.

† Including "Engine and Van" miles.

The overhead equipment for all running lines and for a proportion of the sidings would be of the catenary design; where practicable a simpler design would be adopted for groups of sidings where the conditions of working do not justify the higher cost of the more elaborate system. In many places slight alterations to existing structures would be necessary to provide sufficient space for the overhead lines; these alterations would involve the reconstruction and lifting of bridges, the lowering of tracks at a few points, and the removal of smoke boards. This matter has been examined in detail by the Chief Engineer, and his estimate of the cost of the alterations is given in Table VI. below.

It is important that with high speed working the overhead line structures should not obscure the signals. It is not always possible, even if it were desirable, to design the structures so as to permit a clear view of the signals from an adequate distance, and it would be necessary to provide special daylight electric signal lamps at many points. An estimate for these, for the alterations to existing signals and gantries, and for the provision of route indicators at junctions has been prepared by the Signal and Telegraph Engineer, and is included in Table VI. The present system of direct current track circuits would have to be altered to the alternating current system, as the rails would be used for the return in the main circuit. Alterations would also be required to the telegraph and telephone circuits to prevent interference with the new power lines. These would involve the provision wherever necessary of an insulated metallic return and the removal of earth connections from the rails; some of the present wires would have to be moved, and others at crossings cabled. The estimated cost of these alterations is given in Table VI.

#### *Power Supply and Substations.*

In accordance with the Committee's instructions, we have assumed that power for all purposes connected with this scheme would be purchased from the Central Electricity Board, who would provide the substations and wherever necessary, the secondary transmission lines between them and the grid substations, the Railway operating and maintaining the traction substations and paying the local rates thereon. The supply would thus be given by the Board for traction purposes as direct current at 1500 volts, and for other purposes as three phase or single phase alternating current at 6600 volts or other suitable pressures. The terms for the supply would be the subject

of negotiations and would naturally depend on a number of conditions, but we are authorised by the Board to state that the price would not be less than 0.5d. per unit. For the purpose of this report we have used this figure in our calculations.

The traction substations would be located at intervals of about 12 miles, and would be equipped with converting plant and switchgear for automatic operation on the supervisory control system. We should propose to arrange them in two groups, each group being connected to a control office at a convenient point near the centre. All switching operations in the substations and in the track sectioning switch cabins between the substations would be carried out by the Power Controllers at these two points by means of pilot circuits, which would also serve to indicate the position, whether open or closed, of every switch before and after any switching operation. These pilot circuits, together with two or three pairs of telephone wires to enable the Power Controllers to communicate with the maintenance staff and the Traffic Controllers, would be carried on the structures of the overhead track equipment.

#### *Auxiliary Power Supplies.*

With power at 0.5 penny per unit available at all points on the electrified sections, it would be profitable to utilise this supply for many auxiliary purposes which now take power from various sources, and to convert many steam, gas and oil installations to electric working. For this purpose, all substations would contain two auxiliary power transformers, one for continuous service and one as a standby, and three-phase or single-phase alternating current at 6600 volts or other convenient pressure would be distributed to all points on the electrified lines by an insulated cable, suspended from the track structures or laid along the track. This cable would be tapped wherever necessary for the supply to the new signal lights, the alternating current track circuits, and for lighting and power purposes at the various stations and goods yards. The estimated cost of alteration and conversion has been worked out by the Electrical Engineer in consultation with the Chief Accountant, who have also given us the consumption under the new conditions, and the present and revised costs of maintenance.

#### *Heating of Passenger Trains.*

Provision must be made for heating passenger trains during the winter months, and for a comparatively small scheme as this is, there is clearly no alternative to the system of steam heating which is in use throughout the Railway. It is necessary therefore to provide a boiler for each electrically hauled passenger train of sufficient capacity to heat the coaches to a reasonable temperature in the coldest weather. This boiler can be carried either on the electric locomotive or on a special truck; it can be either coke or oil fired or electrically fitted. Taking all the circumstances into account, simplicity of working, cleanliness, and freedom from fire risks in case of accident, we should recommend that an electric boiler should be included in the equipment of each passenger locomotive, and provision is made for this in the estimates.

#### *Estimates of Capital Expenditure.*

The estimates of capital expenditure are set out in detail in Tables VI and VII. The former shows the expenditure on, and connected with, electrification, apart from locomotives and multiple-unit train equipments; the latter gives the net capital outlay including the charge against the scheme for locomotives, as shown in Table V, and taking into account the credits for plant and other assets released.

Dealing first with the charge for locomotives as set out in Table V, the estimated cost per locomotive of each type has been worked out on the experience of recent contracts, with an allowance for the difference between prices for the home market and for export, assuming that the complete equipment would be purchased from electrical manufacturers, and that the mechanical portions would be built by the Railway in their own shops.

The number of electric locomotives required has been deduced from the engine working on the electrified sections with the revised time tables, with an allowance in each class for spares, inspection and running repairs, and periodical overhaul. It will be seen that in addition to the three motor and trailer coach equipments required to replace those now in service on the Heysham-Morecambe-Lancaster Branch the number of electric locomotives required would be 220. On comparing this with the annual engine mileage for all classes of traffic, viz., 7,830,120, it will be seen that the average annual mileage worked by each engine is only 35,000. This low figure is not due to any conditions inherent in the locomotives. It is well known from practical experience that electric locomotives are capable of working more than twice this mileage. We have therefore analysed the traffic conditions which determine how the locomotives are used. We find that there are a great many short runs for which electric engines must be provided; thus, although the distance from Crewe to Carlisle is 141 miles, the average length of journey for booked electric passenger trains is only 43 miles, and for electrically hauled goods trains 42 miles. It is clear therefore that, as the electrification scheme is restricted to the sections detailed above, there must necessarily be a great deal of lie-over time during which electric locomotives are waiting for trains. Such a state of affairs would not arise if the electrification were more extensive and included all, or practically all, the lines over a large area, as longer engine runs could be arranged, and there would be a better diversity in the incidence of traffic. There are, for instance, a number of electric locomotives which as part of their regular routine lie-over between turns for 15 or 16 hours per day. If adjacent sections were brought into the electrification scheme, a large part of the additional traffic could be dealt with by using the locomotives provided for the present scheme during their periods of lying over.

In order to determine the number of steam engines released, the Railway Officers examined all the workings of engines running either wholly or partially over the electrified sections. These include an engine mileage of about 15,800,000, about 5,800,000 being on sections not comprised in the electrification scheme, and under existing conditions of operation 614 engines are required. Although electrification would eliminate 53 per cent. of this steam worked engine mileage only 235 engines, or 38 per cent. of the existing number, would be released.





assets released. The list of these assets and their values, as given to us by the Chief Accountant, is set out in Table VII., the total credit being £269,608. Thus the net capital expenditure on the scheme is £5,123,370.

**TABLE VI.**  
**ESTIMATES OF CAPITAL EXPENDITURE.**  
*Excluding Expenditure on Locomotives and Multiple Unit Train Equipments.*

Item.	Description.	Estimated Cost.	
		£	£
1	Track equipment of 646.8 miles of running track and 196.5 miles of sidings, including bonding, switch cabins, feeder connections, auxiliary power cable, and pilot and telephone lines.		2,519,550*
2	Alterations to Ways and Works:—		
	(a) Bridges and Structures ... ..	150,635	
	(b) Telegraphs and Telephones, Signals and Track Circuits ... ..	270,230	
	(c) Alterations at Crewe and Preston in connection with engine working	52,585	
			473,450
3	Alterations to running sheds and repair shops ... ..		19,000
4	Control and Maintenance offices, electrical stores, depots and staff quarters		24,750
5	Spare parts and material for locomotives, multiple unit train equipments, track equipment and sub-stations.		130,000
6	Alterations to existing auxiliary power and lighting installations ...		125,000
7	Contingencies, engineering expenses and interest on capital during construction.		365,000
	Total ... ..		£3,656,750

\* This estimate is calculated on a basis price for copper of £70 per ton, and is subject to adjustment at the rate of £5,328 for every £1 per ton by which the basis price differs from £70.

**TABLE VII.**  
**NET CAPITAL EXPENDITURE.**

	£	£
Gross capital expenditure (excluding locomotives), Table VI ... ..		3,656,750
Net charge for locomotives, Table V... ..		1,736,228
Total ... ..		£5,392,978
<i>Less.</i> Credits.		
Stocks of Coal and Stores ... ..	30,646	
Spare parts for locomotives, work in progress, etc. ... ..	104,520	
Water troughs ... ..	2,486	
Auxiliary power installations ... ..	131,956	
		269,608
Net capital expenditure ... ..		£5,123,370.

*Working Expenses.*

The comparative annual costs of the traffic that would, when the scheme is put into operation, be worked electrically, are set out in Table VIII. The steam figures have been supplied to us by the Railway Officers, and we have ourselves estimated the various items of electric working cost (except the items for wages of locomotive crews and auxiliary power supplies which are referred to later) basing our estimate on the operation of similar equipment on electric railways elsewhere.

Before dealing in detail with the various items, we would point out that since this is only a partial electrification, and since there will be many steam trains still in use on the section and many steam locomotives stationed at the various sheds, it has been necessary to leave in certain costs which would have been eliminated had the electrification been complete. Speaking generally these are the costs designated by the Railway Accountants as "non-variable" costs, and they apply, as pointed out later, to expenses in connection with coaling and watering facilities, and engine sheds.

Item 1.—Locomotive fuel or electric power.—The cost of fuel for the steam service is based on the present price of coal, and includes carriage, not at the full public rate, but at the rate which it is estimated covers the actual cost to the Railway for performing this service.

The cost of electric power is based on the total ton mileage of each class of traffic and on the estimated consumption of energy per ton mile. This estimate takes into account the tractive resistances of the different kinds of rolling stock, including the locomotives, at the normal working speeds, the gradients, the average weather conditions, passenger train heating, and the losses in the overhead line and rails. The annual consumption ascertained in this manner has been charged at the rate of 0.5d. per unit, the total cost being £242,710.

Item 2.—Water for locomotive purposes.—The water required for washing down rolling stock has not been included on either side, and the cost for steam working is that for boiler water for steaming and washing out. The only requirements for water for the electric service will be for the small train heating boilers, and this amount is so small as to be almost negligible. A figure for this has been included, but the bulk of the £4,990 which appears in the table is due to "non-variable" charges on watering appliances which, although they will not be required for the electric engines, must be retained for the operation of the remaining steam service over the Line.

TABLE VIII.

## COMPARATIVE WORKING EXPENSES, STEAM AND ELECTRIC.

Item.	—	Steam.		Electric.	
		£	£	£	£
1	Locomotive fuel (including haulage and handling) or electric power.		222,496		242,710
2	Water for locomotive purposes ... ..		14,115		4,990
3	Lubricants for locomotives ... ..		5,916		1,500
4	Locomotive stores, clothing and miscellaneous.		8,106		4,850
5	Drivers' and firemen's wages and allowances, including relief and shed drivers and holidays.		143,144		106,631
6	Locomotive cleaning ... ..		13,467		5,600
7	Other shed staff ... ..		24,178		17,300
8	Locomotive repairs ... ..		203,431		86,800
9	Shunting at sheds... ..		6,127		500
10	National insurance and workmen's compensation.		6,216		4,000
11	Maintenance and operation of sub-stations.		1,547		10,800
12	Maintenance of track equipment ... ..		1,152		43,100
13	Auxiliary power supplies and maintenance.		117,640		82,946
14	Depreciation:—				
	Locomotives ... ..	31,871		36,975	
	Track equipment ... ..	292		14,722	
	Sub-stations ... ..	492		—	
			32,655		51,697
	Total ... ..		£800,190		£672,424
		Difference in favour of electrification ... ..		£127,766	

Item 3.—Lubricants.—The quantity of oil for lubricating the electric engines has been estimated from figures in our possession relating to experience on a number of electrified railways.

Item 4.—Locomotive Stores, Clothing, Miscellaneous.—Under this heading are a number of items such as materials for cleaning, boiler washing, fire lighting, engine lamps and tools. Some of these will be eliminated, and some reduced. The cost of clothing will also be less, not only on account of reduced personnel, but on account of the cleaner nature of the work.

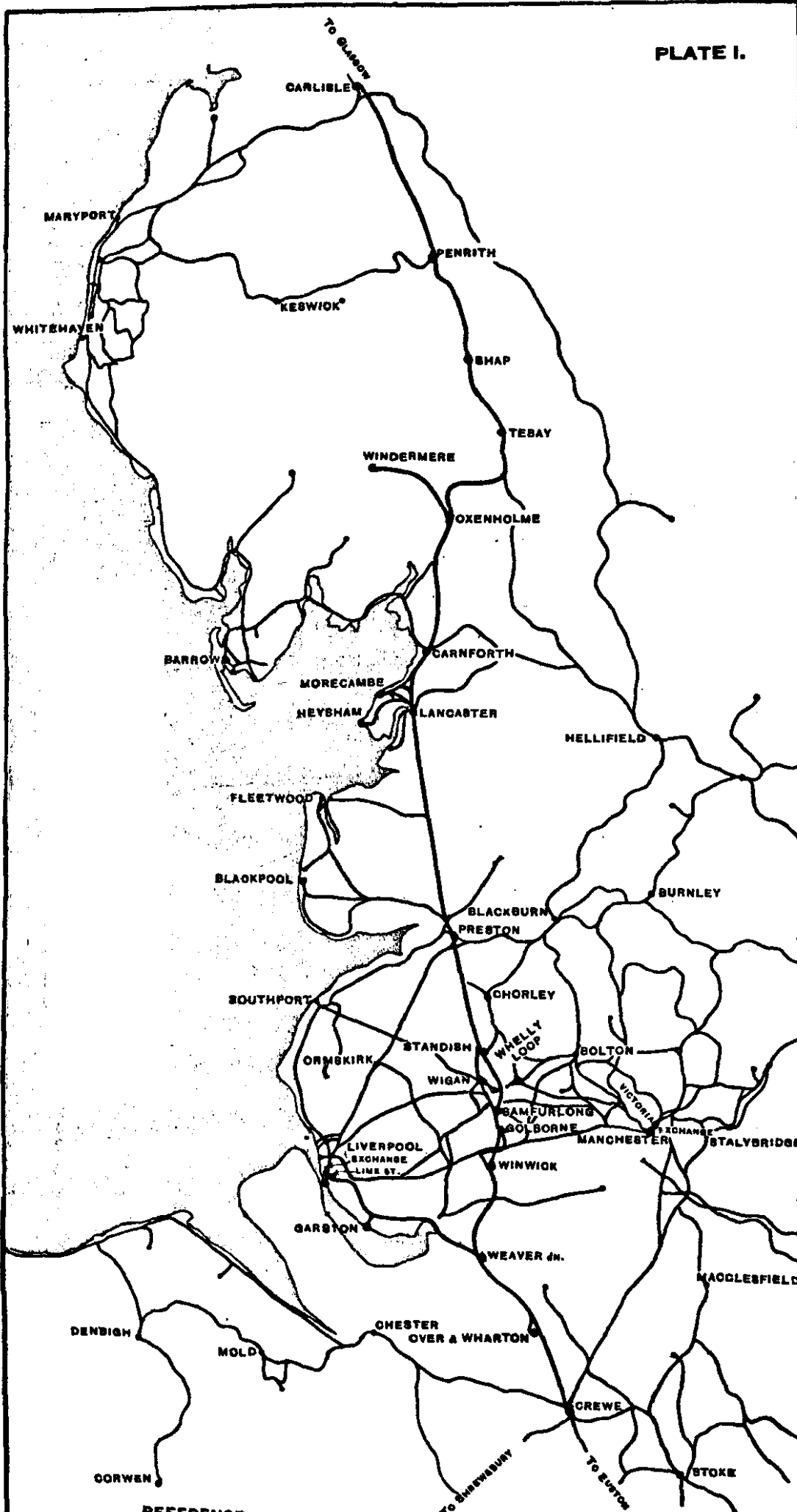
Item 5.—Drivers' and Firemen's Wages.—The cost of these wages for the steam service was ascertained by the Chief Accountant, and the cost for the electric service was estimated by the Chief General Superintendent's Department. This estimate was worked out in detail from the revised time tables, applying the same wage rates as for the present steam service.

Although the speed of the electrically hauled trains of all classes is substantially higher than the present speeds, this is not reflected to any marked extent in the wages of the enginemen. This is due to the fact that owing to the smallness of the section, and the shortness of the average engine run to which we have referred above, the arrangement of crews is not as economical as could be desired, and the actual cost of the steam and electric working (assuming the same number of men to be on the engine in both cases) is not very different. With the elimination of the coal-fired boilers, there would no longer be any necessity to provide two men on each locomotive. The equipment requires no attention during running, and one man is sufficient for the duties of driving. It is already customary to put one man in control of multiple-unit electric trains, and on electrified main lines on the Continent the principle is being extended to all trains excepting the long distance passenger expresses. To safeguard the train in the event of the motorman or driver being taken ill, a "dead man handle" would be provided, which would automatically cut off the power and apply the brakes. This device is available in different designs suitable for suburban multiple-unit trains, and for electric locomotives. The estimates have been worked out on the assumption that there would be a single driver on each multiple-unit train and goods train, but that there would be two men on each locomotive-hauled passenger train, though the second man need not necessarily be on the locomotive the whole of his time.

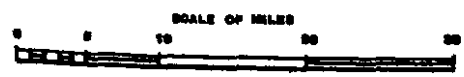
Item 6.—Locomotive Cleaning.—With the elimination of coal and steam, the expenditure on staff for cleaning engines would be considerably reduced. The figure included in Table VIII has been estimated on the basis of the staff employed elsewhere for similar work.

Item 7.—Other Shed Staff.—Boiler washing will be eliminated in the case of electric engines (except for a small amount in connection with the train heating boiler). The remainder of the cost under this item refers to foremen, oilers, and clerical and other labour at the sheds. In view of the fact that the electric engines visit the shed at much longer intervals than the steam locomotives, the staff required would be materially reduced by electrification.

Item 8.—Locomotive Repairs.—The figure for electric working includes all the work of repairs whether light or heavy and whether carried out at the running shed or the repair shop. We have made a special study of the cost of such work under various conditions and we are



REFERENCE:—  
 ROUTES CONSIDERED IN THE REPORT ———  
 OTHER ROUTES - - - - -  
**L. M. S. RAILWAY.**  
**MAP OF PART OF THE SYSTEM.**



confident that our estimates can be realized in practice. For the "non-variable" portion of workshop expenses we have taken the figure included in the costs for steam working although we consider that this is rather larger than would be necessary if the scheme had been part of a general electrification of the railways. This has already been referred to above.

Item 9.—*Shunting at Sheds.*—Shunting at sheds includes a great many movements mainly concerned with the coaling and watering of engines. With electric working the amount of shed shunting is very substantially reduced.

Item 10.—*National Insurance and Workmen's Compensation.*—The expenditure under this head relates to engine crews and to all men in workshops and in engine sheds, and has been estimated on the same basis as the cost for steam working.

Item 11.—*Maintenance and Operation of Substations.*—An estimate of the staff required for this purpose has been made and the costs are based on this, with an allowance for maintenance materials.

Item 12.—*Maintenance of Track Equipment.*—In this case also we have worked out a complete organisation based on what has proved to be necessary elsewhere, and the costs include the salaries, wages and other expenses of this organisation, and the necessary maintenance material. In estimating the expenditure on material, we have considered it prudent to provide for the replacement of the contact wire (the only part subject to wear) at the end of 20 years.

Item 13.—*Auxiliary Power Supplies.*—Information has been supplied to us as to the present cost of electricity used for auxiliary power purposes, and the cost of electricity, oil, gas or other fuel used for lighting and heating. These costs, together with the maintenance expenses of the various installations are included in this item for steam working. At our request the Electrical Engineer and the Chief Accountant have estimated the annual consumption of electricity for these services as well as the maintenance expenses which would be incurred if the power were taken from the traction substations. The total annual cost, on the basis of 0.5*d.* per unit, is included in this item for electric working. The capital cost of the change-over has been included in Table VI.

Item 14.—*Depreciation.*—For the electric locomotives we have taken an assumed life of 33½ years. For line equipment, which consists mainly of steel structures and copper wires, we have allowed a life of 50 years, and for the switchgear in the sectioning cabins a life of 33½ years. Scrap value, where this is appreciable, has been deducted and the depreciation worked out on original cost less scrap value, on the basis of a 4 per cent. per annum sinking fund.

*Summary of Comparative Working Expenses and the Financial Result.*

The total of the comparable items of working expenses with steam operation is £800,190, and with electric working £672,424. The annual saving due to electric working is therefore £127,766. This is equivalent to 2.5 per cent. on the net capital expenditure of £5,123,370. From this saving of £127,766 per annum must be deducted the amount payable in local rates on the substations and track equipment, and the balance would go toward the payment of interest on the net capital outlay.

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In conclusion, we would like to express our appreciation of the assistance which has been given to us by the officers of the Railway who have spent a great deal of time in studying the problem and in preparing the information which we required for our calculations.

MERZ AND McLELLAN.