1908
NEW ZEALAND.

CHRISTCHURCH-LYTTELTON RAILWAY

(REPORT ON PROPOSAL TO ELECTRIFY THE).

Return to an Order of the House of Representatives dated the 2nd July, 1908.

Ordered, "That there be laid before this House the report which has been prepared upon the proposal to electrify the Christchurch-Lyttelton Railway line."—(Mr. GRAY.)

The GENERAL MANAGER, Railways Department, to the Hon. the MINISTER FOR RAILWAYS.

Railways Department, Head Office, Wellington, 7th February, 1908.

Memorandum for the Hon. the Minister for Railways.

Proposed Electrification of Christchurch–Lyttelton Railway.

IN accordance with your instructions, I have had a report made regarding the electrification of railways, more particularly of the Christchurch–Lyttelton line. The electrification of this line is demanded chiefly on account of the smoke-nuisance in the tunnel. This can be dealt with by the use of oil fuel. The cost, however, would be heavy, although it would be very much less than the increased interest-charges that would have to be met if the line were electrified.

In the event of the Government deciding to electrify the line, we should, I consider, follow the example of Victoria, and employ a special expert to visit the Dominion and make himself acquainted with the physical characteristics of the line.

T. RONAYNE,
General Manager.

Wellington, 20th December, 1907.

General Manager, Wellington.

Proposed Electrification of Christchurch–Lyttelton Railway.

IN accordance with our instructions, we forward herewith report on the proposed electrification of the Christchurch–Lyttelton Railway.

In dealing with this subject we have thought it desirable to first describe the systems in use; we have then given examples of installations in various parts of the world, with costs and details of working, and have applied this information to the Christchurch–Lyttelton proposals.

Should, however, the Department decide on the electrification of this or any other section of the railways, we would respectfully suggest that an engineer of standing, with a technical knowledge of the subject, be engaged to report and advise on the methods of working to be adopted, and to give estimates of the cost.

JOHN COOM,
Chief Engineer.
A. L. BEATTIE,
Chief Mechanical Engineer.

PROPOSED ELECTRIFICATION OF THE CHRISTCHURCH–LYTTELTON RAILWAY.

SYSTEMS.

The various systems of electric traction, or the different methods of establishing communication between the fixed power-station and the moving vehicles, are,—

(1.) The overhead, or trolly system.
(2.) The underground, or conduit system.
(3.) The surface-contact system.
(4.) The accumulator system.
(5.) The third-rail system.
(6.) Combination of either of the above systems.

The adoption of the overhead system for heavy main-line railway traffic is as yet largely in the experimental stage, and there is very little practical information available on the application of this system to such purposes. It is, however, worthy of note that several large installations are now in progress in America, the results of which are being anxiously awaited.

Up to the present, where existing railways have been converted from steam to electric traction, the third-rail system has been adopted in nearly every case.

The chief disadvantage in the use of a third-rail system is the liability to personal accident though contact with the live rail. This, however, has of late been reduced to a minimum by the adoption of improved methods of protection.

Currents, etc.

The kinds of current used are,—

(1.) Continuous, or direct current.
(2.) Alternating current, three-phase.
(3.) ,, ,, single-phase.

The only system, up to the present, adopted in England is the continuous or direct current, but a suburban portion of the London–Brighton line is now being installed with the single-phase alternating-current system.

In America and some places in Europe each of the three systems is being tried. The opinions of experts are divided as to the best system of supply of current for heavy railway traction.

The following remarks indicate some of the advantages and disadvantages of the various methods:—

(1.) *The Continuous Current System.*

Has proved extremely successful for tram-lines, tubes, and short railways. On tram-lines the current can be conveyed to the cars through a trolly-wire, but with heavier traffic a third rail is required to carry the larger currents necessary. There are three drawbacks to the use of continuous currents on railways, and particularly on main lines,—

(*a.*) The third rail is very much in the way, very difficult to find room for, and, unless fully protected, is dangerous.
(*b.*) Rotary converters for converting the high-tension distribution-current into low-tension working-current used in the third rail have to be distributed along the line. This adds to the cost of supervision, and there is a greater possibility of breakdown.
(*c.*) The expense of the distribution system.

(2.) *Three-phase.*

This system has the advantage over the continuous-current system in that high-tension currents conveyed by trolly-wires can be used, the third rail is avoided, and there is no running machinery along the line. There are, however, two drawbacks to the three-phase,—

(*a.*) The motor has an uneconomical start. Either resistance must be used up to full speed, or the rather troublesome "cascade system" adopted, with which half the motors are idle at full speed.
(*b.*) Two trolly-wires are needed, which make all junctions, &c., complicated, and nearly double the difficulty of overhead construction.

(3.) *Single-phase.*

This is the newest system, and appears to be the most suitable for railway traction. It has none of the disadvantages mentioned above as appertaining to the continuous-current and three-phase systems.

There is no third rail, no running machinery along the line, and the distribution is the simplest possible. The motor gives a good starting tractive force, and starts more economically that continuous-current or three-phase motors. Only one trolly-wire is used, and there is therefore no difficulty at the junctions.

Power.

The power used in the generation of electric current for tramways and railways is obtained in different ways—viz., by water, steam, and oil or gas engines.

Examples of Installations.

Lancashire and Yorkshire Railway.

The electrical energy is generated at three-phase alternating current of 7,500 volts pressure, and transmitted to substations, where the voltage is stepped down by statics, and transformed by rotary converters into direct current of 650 volts pressure, the maximum voltage at the train being 600.

New York – New Haven and Hartford Railroad.

The New York Central part of the New Haven system is operated on the direct-current system; the remainder of the line is on the alternating-current system.

Electric Railway connecting Bonn and Cologne.

This railway, which has recently been opened, is of special interest in that it affords an example of the use of high-pressure continuous direct currents for electric traction. The length of the line is about seventeen miles, and at Bonn and Cologne it connects with the tramway systems of those towns, which are operated by continuous current at 550 volts. The system adopted, therefore, is to use continuous currents, at 990 volts in the open country, and at 550 volts in the towns.

Simplon Tunnel.

The traffic through this tunnel is worked by electric locomotives operated on the three-phase alternating-current system at pressure of 3,300 volts, the current being supplied from two water-power generating-stations, one near each end of the tunnel.

Electric Traction on the New York Central.

What is commonly called the Electric Zone on the New York Central comprises at present the line from the Grand Central Station to Wakefield, on the Harlem Division, a distance of thirteen miles, and from Mott Haven to Kingsbridge, on the main line, four miles, making a total of seventeen miles. The Electric Zone will eventually be extended on the main line to South Croton, and on the Harlem to North White Plains, and when this is done there will be fifty-two miles under electric traction. The track-mileage, including yard-tracks, now amounts to eighty-five miles, but when the extension of the electric system is completed there will be 292 miles in all. The rails weigh 100 lb. per yard.

The power-house is at Port Morris, and at that point electricity is generated as an alternating current at 11,000 volts pressure, and the current is carried to four substations, where the alternating three-phase current is transformed to direct current at 666 volts, which is supplied to the third rail in that form for use by the electric locomotives.

At each substation there is an auxiliary battery equipment by which it is intended to supply current in case of any serious derangement taking place at the central power-station.

In addition to the electric locomotives for through train service the company has 125 all-steel multiple-unit motor-cars for suburban service, each with a normal capacity of 400-horse power, and weighing each about 53 tons. There are fifty-five all-steel multiple-unit trailer cars for suburban work, each weighing about 41 tons. Six all-steel multiple-unit motor combined baggage and express cars, each of 400-horse power capacity, complete the equipment, which makes in all 221 vehicles for exclusively electric operation.

The signal system will require the use of alternating current for track circuits, while the propulsion system, by which the locomotives and motor-cars are driven, is direct-current.

The Electrification of the Hammersmith and City (Joint Great Western and Metropolitan) Railway.

The joint advisory committee appointed by the two companies to determine the system to be used on the circle recommended the adoption of the three-phase alternating-current traction. This decision was supported by the Metropolitan Railway; but the Metropolitan District Company, acting under American influence, advocated a direct-current system, three-phase transmission being used to substations, where the current would be changed to continuous. In 1901 the dispute came before Parliament, who referred the question to a special tribunal, to report to the Board of Trade which of the two systems was to be used. The arbitrator was the Hon. Alfred Lyttelton, K.C., M.P., late Secretary of State for the Colonies. A great mass of evidence, expert and otherwise, was heard, which indirectly must have been of great benefit to the electrical world in general. Subsequently Mr. Lyttelton presented his report, recommending the adoption of the continuous-current system, on the ground that it had been well tried, whereas the Ganz system was only in an experimental stage. The Board of Trade, acting on this report, decided that the continuous-current system should be used in the Inner Circle and lines in connection.

The engines are of a forced-lubrication high-speed type, developing 1,080 brake horse-power each normal load, and 1,400 brake horse-power at maximum load, and are coupled to eight three-phase generators, each developing 750 kw. normal load at 6,300 to 6,600 volts, and capable of a 15-per-cent. overload for one hour.

There are three substations, located at convenient points of distribution on the system. At these the alternating current is reduced in pressure from 6,600 volts three-phase, converted into 600 volts direct current, and fed by low-tension cables into the collector rails on the railway.

Twenty trains have been built for the new service by an outside firm. Each train consists of six coaches, two being motor-cars and four trailers, and is capable of seating 320 passengers. The type adopted is similar to that adopted on the Inner Circle, and is designed for a schedule speed of sixteen miles an hour, including stops.

Electrification of Sixty-seven Miles of Railway, Italy.

High-tension three-phase railway with cascade motors (Ganz system).

Trains are made up of old rolling-stock plus the new motor-cars and new goods-locomotives.

Goods-locomotive weighs 46 tons, and is capable of starting a 270-ton load on an up grade of 1 in 90, or of drawing 450 tons at eighteen miles per hour uniform speed on same grade.

Total maximum horse-power of four motors in each locomotive is 600. The four motors in each motor-coach are in two cascade pairs, and at half-speed they together can exert 300-horse power. Other locomotives have been put on line to draw express trains of 250 tons at forty-four miles per hour, and goods-trains of 400 tons at twenty-two miles per hour.

The energy is brought from the central generating-station along the line as three-phase current at 20,000 volts and 15 per second frequency, is transformed at substations without rotary converters to 3,000-volt three-phase current, collected from trolly-wires, and led direct to motors.

Power is obtained from turbines driven by water from a river. Turbines develop 7,500 normal and 10,000 maximum horse-power.

The total cost of the electrification of this sixty-seven miles was about £248,000. Of this, £100,000 was spent on the hydraulic-power works, which are capable of at least three times as much power-development as at present called on to provide; £52,000, electric rolling-stock; £68,000, electrification of line; £28,000, central-station machinery.

The two $\frac{5}{16}$ in. trolly-wires used for the 3,000-volt three-phase current cost £130 per mile, while for the same horse-power transmitted by 700-volt continuous current the cost of copper conductor would be £1,300 per mile.

Steel-rail conductivity would cost about £900 per mile.

The Ganz high-tension three-phase induction-motor system is being used for eighteen miles of railway in North Wales and in Canada.

Wannsee Electric Railways, Berlin.

Estimated capital cost of electrification of 11½ miles of double track, with two miles of sidings (third-rail system):—

	£
Central station	65,000
Batteries, 3400 kilowatts	21,050
Transmission	40,000
Twenty-four locomotives of 300-horse power, at £2,250	54,000
Repair-shop	2,500
Sundries	2,450
Total	185,000

Current obtained from a Siemens and Halske outside armature dynamo, giving 400 amperes at 750 volts, which, however, is run at 900 volts when batteries are being charged. This is driven by a 500-horse-power condensing-engine.

Thunn and Burgdorf Three-phase Railway, Switzerland.

The normal line tension is 750 volts, two phases of the current being collected from two overhead copper wires, while the third phase travels by the rails. The high tension is at 16,000 volts.

Six turbines, each of 900-horse power.

There is one special point about the design of the rail third-phase return that is worth noting. Copper bonds are done away with, and the only bonds are the fish-plates.

Motor-coaches weigh 32 tons empty, and have four 60-horse-power three-phase motors.

Locomotives are driven by two motors of 150-horse power each, weight 30 tons.

Capital outlay on construction,—

	£
High-tension line with branches to transformer substations ...	5,600
Fourteen transformer stations, each 450 kilowatts	6,400
Contact overhead duplex line and return-rail bonding	14,000
Station-lighting, and repair-shop	800
Six motor-coaches and two locomotives	9,400
Reserve fund	1,200
Total	37,400

Central London Electric Railway: Central-Third-rail System.

Current to motors, 500-volt, continuous.

Each train is made up of seven cars, the front and the last being motor-cars A motor drives each axle of the front bogie truck on the car, so that four motors drive each train, giving in all 500 nominal horse-power.

The central station contains six main three-phase generators, driven by horizontal cross compound Corliss valve jet condensing-engines.

Metropolitan Railway and Metropolitan District Railway: Third-rail System.

Total route-length of Metropolitan Railway is sixty-seven miles, of which twenty-six miles have been electrified.

The Metropolitan District route is about thirty-three miles. The line-current is supplied to cars at between 500 and 600 volts.

The normal weight of train is 150 tons.

Power is at present being provided for thirty-eight full-sized trains running simultaneously on the whole Metropolitan system.

The engineer's rough estimate of the total running-expenditure is £20 per train-ton year.

The rolling-stock of thirty-eight trains will cost about £346,000; power-station about £174,000.

The complete electrification of the line, including central and substations, feeders, rails, and rolling-stock, will cost over £1,250,000.

Power used for Metropolitan Railway electrification turbines, 5,000 brake horse-power, run at 1,000 revolutions per minute. Westinghouse generators, 3,500 kilowatts, each at a voltage of 11,000.

It has been decided that the electric trains for the Metropolitan District Railway should be worked on the Sprague-Thomson-Houston system of multiple-unit train-control. Motor-cars on this system have already been substituted for separate locomotives on the Central London Railway, in order to overcome vibration troubles, and are also being introduced on the Great Northern and City Railway.

Each train will be composed of three motor-cars and three or four trailers, all being under the control of one driver, and the motor-car portion will be separated from the passenger part of the car by means of a fireproof steel partition.

New Metropolitan Trains.

Cars, 52½ ft. long. Approximate weight, 39 tons. Each motor-car, of which there are two in a train of six coaches, is equipped with four 150-horse-power British Westinghouse railway motors, one for each axle of the truck. There will be the unusual amount of 1,200-horse power available for propelling each train. System, third-rail; 11,000 volts three-phase current, transformed to direct current at 600 volts by rotary converters.

Liverpool and Southport Line.

Length of line, Liverpool to Southport, 18½ miles.

Steepest grade, 1 in 85.

Sharpest curve, 7 chains.

Electrical energy is generated at three-phase alternating current of 7,500 volts pressure, and transmitted direct to substations, and transformed by rotary converters into direct current of 650 volts pressure, the maximum voltage at the train being 600.

Machines installed, four 1,500-kilowatt units, three of which under normal conditions meet the requirements. In addition there is a fifth unit of 750 kilowatts.

Motive power, four main engines of horizontal-cross-compound type, and one vertical-cross-compound type, running at seventy-five revolutions per minute. Nominal load of each engine, 2,310-horse power, with a pressure of steam of 150 lb. per square inch.

Total weight of four-car train, 140 tons. Each motor weighs 44 tons, and trailer 26 tons.

Electrification of the Long Island Railway: New York City and Suburban System of 97½ Miles of Track.

System adopted, third-rail contact; direct current of 600 volts for propulsion, and alternating current at 11,000 volts for transmission to the substations.

Current generated by three Westinghouse-Parsons turbine units of 5,500 kilowatts capacity each.

Trains are of three, five, and eight car-units, the number of motors to each being two, three, and five respectively. Each motor-car has two propelling motors of 200-horse power each; the car weighs 83,000 lb. (37 tons), and is capable of maintaining a speed of fifty-five miles an hour.

TRAIN-SERVICES, ETC.

Among the advantages gained by electrical operation is the better use which can be made of terminal facilities during rush hours.

As an example of this, Mr. Aspinal, of the Lancashire and Yorkshire Railway, instanced what he called the platform operations required for steam-trains and for those electrically driven when entering or leaving a terminus. With steam-trains, the first platform operation consisted in the train coming in, the second was the following-in of the locomotive which was to take out the train, the third was the departure of the train, and the fourth was the backing-out of the locomotive which had brought the train in. These four platform operations required eight signal operations.

The same train, if handled electrically, would require only two platform operations and four signal operations: the train comes in — that is one operation; the motorman then goes to the other end of the train and takes it out—that is the second operation.

Not only was the terminal of the Liverpool and Southport used to greater advantage by the employment of electric traction, but a very important gain was made by the very possession of the facility to handle traffic—more traffic was offered.

It would almost seem to be an axiom in railroad operations that the more a line can do the more it will be expected to do. This road had four tracks for a certain distance out of Liverpool, and when electrification first took place the business offered was such that it could be handled over two of these tracks, and the other two were set aside for freight service with steam locomotives. The passenger-travel, however, soon became so large that it necessitated the equipping of the two freight tracks with the third rail, and the use of them for passenger traffic in the rush hours. One might fairly apply Hamlet's words to the travelling public, for it seemed as if increase of appetite had grown by what it fed on. In this way the greater cost per ton-mile run under the electrical system was more than offset by the larger paying volume of traffic which the road was able to handle.

Mr. Wilgus, in his remarks in the discussion of Mr. B. G. Lamme's paper dealing with the electrification of a part of the New York Central, also had in mind the ability of the electrically equipped road, under certain circumstances, to attract passenger traffic, and so to augment the company's receipts. This, it seems, is the *raison d'être* for electrical equipment, and, failing this, the alteration from steam to electricity would be probably a costly and useless experiment. In concluding his remarks he said, "It appears that the purpose of a change of motive power for heavy railway service from steam to electricity is to abate the smoke-nuisance and improve the passenger service so as to make travel more attractive. The electric system which is adopted, whether direct or alternating current, must employ the safest appliances known to the art, it must have all possible safeguards against interruption due to trouble in the power-station and on the line, it must employ well-tried apparatus that has passed beyond the experimental stage, and it must be thoroughly flexible so as to afford the travelling public the advantages that are denied with steam operation. The use of any system which does not possess these qualities will burden the corporation adopting it with a heavy expense, for which there is no adequate return. Whether the system shall be alternating or direct current depends entirely on the development of the art, from a practical standpoint and the local conditions. The more congested the traffic, the more necessary the adoption of the system that will be least in danger of failure and best adapted to public demands."

FINANCE, COST, ETC.

Referring to some remarks reported to have been made by him in Melbourne on the subject of the electrification of suburban railways, Mr. Johnson, Commissioner New South Wales Railways, said "he had not been able to make any investigations in Australia, and therefore had formed no opinion in relation to this country. His observations were of the position of affairs in England only, and there he recognised difficulties of cost in the way of electrification which were well-nigh insurmountable."

The first cost, also the maintenance, are both considered to be in favour of the third-rail system when the overhead system requires to be utilised for heavy traction.

It is considered more economical to build new cars complete for electric traction than to convert the ordinary cars.

The cost of electrifying the line-work only (third-rail system) on the North-eastern Railway was about £6,500 per mile.

No definite particulars of the cost of the overhead system for cases providing for heavy goods traffic are obtainable, as practically very little has as yet been done in the way of handling such traffic by that system.

Some experts estimate the cost of overhead equipment to provide for heavy goods traffic as high as the third-rail system; others again estimate as low as £2,000 per mile for a double track; and the general opinion appears to be that it might cost anything from £2,000 to £6,000 or £7,000 per mile of double track, according to local circumstances.

Mr. W. E. Langdon, electrical engineer of the Midland Railway, in a paper read at the Institute of Electrical Engineers, estimated the total equipment for conversion from steam to electric traction at £9,000 per mile, and some engineers have estimated as low as £5,000; but it is worthy of note that Mr. J. A. F. Aspinall, general manager of the Lancashire and Yorkshire Railway, reported at the Railway Congress at Washington that the total cost on their lines had been £20,000 per mile (but gave no details of what this included), and that the cost of working was quite as high as by steam after making proper allowance for the depreciation of the more costly electric plant. The North-eastern Railway gives the cost of working by electric traction as about half the cost of steam; but neither give the full details of what is included.

In speaking of the electrification of the Liverpool and Southport Railway, which is one of the Lancashire and Yorkshire lines, Mr. Aspinall admitted that the change had been made not with any idea of economy of working but of securing better results. He said his company did not expect to save money, they expected to make money; and these he considered were very different things. Certain expenses more or less offset one another, but experience had shown that it cost more money to work the line by electricity that it had when locomotives were used.

The approximate figure which Mr. Aspinall gave for the electrification of such a line as the Liverpool and Southport was in the neighbourhood of about £20,000 per mile, which he believed was roughly about three and a half times that required for steam traction. Another interesting point brought out on that line was that the weight of what he called the locomotive equipment of the electric train was not any less than it would be with steam locomotives. In main-line work the total weight of motors, controllers, and the electric equipment in general about equals, if it does not exceed, the weight of the ordinary train with the steam locomotive attached.

Extract from the Railway Gazette, *dated 2nd November, 1906.*

In preparing an estimate of the comparative cost of electric and steam working upon an existing and up-to-date line worked at present by steam it is important to clearly analyse the necessary capital outlay in such a way as to favour neither system.

The capital expenditure involved in making the change to electrification may generally be divided as follows:—

(*a.*) Capital which has been expended on the existing system and may be no longer useful.
(*b.*) Additional capital outlay necessary in connection with the electrification.
(*c.*) Capital outlay already incurred, but which can be transferred to another portion of the system worked by steam, and hence be credited to the cost of electrification.

The following hypothetical estimate is given as illustrating the chief items which have to be taken into account in considering such a proposition:—

Estimated capital expenditure on railway ten miles long (twenty miles single track) with 100 trains running each way per day:—

(*a.*) Capital expenditure of existing steam system,—

Train-miles per annum = 100 × 2 × 10 × 340	68,000
Number of locomotives, assuming each to run 17,000 train-miles per annum	40
Number of trains at 25,000 train-miles per annum each, say... ...	27
Carriages at 7 per train	189

	£
Cost of 40 locomotives at £2,000 each	80,000
Cost of 200 carriages (189 plus 11 spares and specials) at £900 each ...	180,000
Engine-sheds, repair-shops, with hydrants and ash-pits	20,000
Two turntables	1,200
Sidings and coal-wharves	6,800
Water-cranes and connections	2,000
Total	290,000

(*b*.) Capital expenditure in connection with electrification,—

Number of coaches at 29,000 train-miles per annum (half motors and half trailers)	168

	£
84 motor-coaches at £2,000 each	168,000
Cost of 84 trailers (including wiring) at £1,000 each	84,000
Addition to existing sheds	10,000
Third rail and bonding running-rails (running-rails used as returns)...	16,000
Low-tension cables	5,000
Total	283,000

This, of course, does not include the cost of substations, it being assumed that power is purchased from some outside source, as is done on the District Railway and North-eastern Railway.

As regards the rolling-stock, it is assumed in making these estimates that the trailers could be taken from the existing stock of carriages, and that one-half of the remaining carriages displaced could be used up elsewhere on the steam system and the remnant be written off at half their original cost. It is also estimated that one-third of the locomotives displaced could be used elsewhere, and the remaining two-thirds could be written off at half their original cost, while the engine-sheds, turntables, hydrants, &c., could be written off at half their original cost.

(*c*.) Capital expenditure to be credited to electrification,—

—	Written off from Renewal Fund.	Transferred from Steam Lines.	Used for Electric Service.	To be wiped off.	Total.
	£	£	£	£	£
Locomotives	25,000	25,000	...	30,000	80,000
Carriages	23,000	47,500	75,500	34,000	180,000
Sheds	10,000	...	...	10,000	20,000
Turntables	600	...	...	600	1,200
Coal-sheds	1,000	...	...	1,000	2,000
Water-cranes	3,300	...	...	3,400	6,800
Total	62,900 (say 63,000)	72,500	75,000	79,000	290,000

The capital charges are probably the more difficult thing to estimate, as considerable numbers of estimates of operating-costs have been published, and we have the actual figures of electrical operation in England before us, although these have not been published. It is these capital charges which most electrical experts totally fail to properly appreciate, unless they have actual experience of the results obtained on electrified lines. In order, however, to prepare an accurate estimate of operating-costs for electric working it is necessary to carefully avoid making comparisons between two- and three-coach electric trains and nine- or ten-coach steam trains. Neglect of this renders a great many of the comparative figures between electric and steam working absolutely misleading. The more satisfactory way is either to specify the weight of the train or to give the figures per ton-mile. Assuming a train to weigh 200 tons, the figures given in our issue of the 19th January (page 8) will as a rule be found approximately correct for the conditions in the South of England.

	Steam Driving. d.	Electric Driving. d.
Fuel (coal at 10s.)	3·75	...
Driver's wages	2·25	0·8
Rolling-stock, maintenance, &c.	7·25	6·5
Superintendence	1·25	0·9
Permanent-way, electrical equipment, maintenance ...	...	2·0
Interest on additional capital, say	...	0·8
Total running-cost per 200-ton train... ...	14·5	11·0

This, it will be noticed, leaves $3\frac{1}{2}$d. per 200-ton train-mile for power. The actual cost of this will, of course, depend on its source. If a thoroughly well-designed power-house be built by a railway company for its own needs, and gives 7,000 to 8,000 kilowatts output, it might be able to produce current at a price, including all costs and capital charges, of possibly 1d. or even $\frac{7}{8}$d., although this would be an unusually fine performance. On the average it may be taken that 60-watt hour per ton-mile will be required from 12 units per 200-ton train-mile. It is thus obvious that the cost of power to the railway company, if it generates it in its own station, will considerably exceed the 3d. which we have allowed; and, in order to keep it down to this figure, current at the outside would have to be purchased at a price of about ¼d. or at the most not exceeding ⅓d. Now, although electrical engineers very frequently mention their costs of production at under ½d., it will nearly always be found that such figures are based upon insufficient capital charges, and the only way in which it is possible to obtain figures at all approaching the ⅓d. required is by having current generated upon such a large scale as would result from the combination of several railway companies, together with a large load for electric lighting and power purposes. It is doubtful if at the present time in London there are any stations producing current, taking all things, including capital charges, into account, at less than ⅞d. per unit. It is obvious that the cost of power at the present time is a very important factor in the electrification problem.

The above figures, of course, only give the actual running-costs. Another estimate of the comparative costs of the two systems is as follows:—

	Steam. d.	Electric. d.
Coal or equivalent electric power	7·25	5·15
Water	0·25	...
Train-crew	6·00	3·35
Maintenance	3·25	2·00
Supplies	0·25	0·10
Total per train-mile	17·00	10·60

This assumes the consumption on the steam locomotive of 4 lb. to 5 lb. of coal, and at the electric power-house of 2 lb. of coal per indicated horse-power hour, taking into account the difference in the quality of the two coals, which would be a saving of about 50 per cent. in favour of electricity.

Another of the savings which is important is that in repairs and maintenance, and the following estimate has been prepared to show this:—

	Steam. Per Cent.	Electric. Per Cent.
Boiler	20	0
Running-gear	20	20
Machinery	30	15
Lagging and painting	12	5
Smoke-box	5	0
Tender	13	0
Total	100	40

Extract from the Railway Magazine *for March, 1905.*

It would be interesting to know whether the directors and officers of the North-eastern Railway are satisfied with the results that have so far attended the electrification of a portion of the system.

The accounts for the past half-year show that the receipts from passengers have increased about £9,000, whilst the cost of electric working has been £22,824. There is a saving of £42,386 in locomotive expenses, and a reduction of train-mileage amounting to 675,232 miles; of this, however, only 232,090 is saving on passenger-train running, so that only £14,500 of the reduced locomotive expenses can be charged as a saving on passenger account.

The balance-sheet therefore works out like this:—

Dr.	£	*Cr.*	£
To Cost of electric traction	22,525	By Additional passenger receipts (all credited to electric traction)	9,157
Six months' interest on capital expended on cost of converting line (£241,376), and rolling-stock, 88 vehicles (say £44,000), at 4 per cent. per annum	5,707	Saving on locomotive expenses	14,500
Loss of first-class traffic, as shown by balance-sheet, because of accommodation not being provided on electric trains ..	6,300	Loss on working for six months	10,875
	£34,532		£34,532

The electric-train-mileage was 588,786, and the electric-car-mileage 2,189,571. The cost of running per electric-train-mile is almost 10d. The locomotive running-expenses per steam-train-mile amount to a trifle over 8½d. per train-mile.

Extract from the Railway Magazine, *December, 1906.*

Just as, ten years ago, electric traction on tramways was creating great interest throughout the country, so now the application of the same system of propulsion for railway purposes is being seriously considered by most of our large railway companies.

It still remains to be shown that it is cheaper than steam traction so far as long-distance lines are concerned; but the writer considers there is little doubt that, for dealing with local traffic in the neighbourhood of large cities, the adoption of electric traction is an absolute necessity if the railways are to retain the traffic which is, so to speak, ready-made and only waiting greater facilities.

Extract from Railway Machinery, *May, 1907.*

While there is no doubt that ultimately electric traction on steam railroads will prove to be as economical and safe as it is convenient and pleasing to the patrons of the railways, it is impossible even for the most ardent advocate of electrification to extract much comfort out of the statements made by the chairmen of the English railroad companies who have undertaken to electrify part of their roads. The *Railway Engineer* states that in one case the shareholders of a British railway were notified by the chairman that electric working is more expensive than steam working, and that at the present time most of the companies having electrified their lines are very much disappointed in that the results have turned out to be considerably different from the estimates given to them by electrical engineers who were supposed to know a great deal about the matter. On the other hand, it was admitted that the cost of working electric traction is constantly being reduced, and that, while the cost is still far higher than the cost of steam traction, when we remember that electric traction on railroads is only in its experimental stage, there are still greater possibilities. There is, however, a consideration in regard to the permanent-way which cannot be too strongly emphasized. The electric rolling-stock cuts the rails to a much greater extent than any stock that has been used in connection with steam-power, and engineers are rather confused at arriving at any definite cause for it. It has been tried to overcome the difficulty by laying down hard-steel rails; but the better way by far would be to, if possible, get rid of the cause rather than to try to meet it by putting down a different kind of rail than has hitherto been necessary. We do not doubt that electric traction on railroads will prove a success in time; but the present results on English roads, where, for instance, in one case the half-yearly dividends on a certain section of the Metropolitan road were cut from 3 to 1 per cent., indicate that there is, as yet, a great deal of improvement to be desired.

Light Railway and Tramway Journal, *10th June, 1904.*

Steam traction costs more or less proportional to the train-mileage. Electric traction is practically proportional to the ton-mileage. Mr. Langdon expects that, with a third-rail system employing a continuous current at 600 volts driven from a primary three-phase current at high tension, the cost will not be much less than £10,000 per mile.

Mr. James Falconer pointed out the special interests attached to the report of the first year under electric traction, but added that the figures must not be taken as being a complete indication of what the results of the innovation would be. The working-expenses, he was bound to say, were not satisfactory, but it must be remembered that they were now giving a much better service, and in comparing costs all the comparisons were in favour of electricity. Thus:—

	Steam Service: Pence per Train-mile.	Electric Service: Pence per Train-mile.
Maintenance of permanent-way	3·9	1·6
Locomotive and generating power	11·3	5·2
Traffic expenses	13·5	7·3
Cost of ventilation	3·4	0·2
Cost of pumping	4·85	1·5
Total working-expenses	41·2	18·2

Application to the Christchurch–Lyttelton Line.

As before remarked, we consider it would be advisable to obtain practical expert advice upon the best system to be adopted as to the cost and methods of working, and we recommend that no further action be taken in the direction of proceeding with the work until this has been done.

In the Christchurch district there have been various proposals for supplying electricity from the water-power sources; but, as no scheme has been definitely decided upon, there is no information as to what would be the actual cost of electric current so supplied.

The question of obtaining electric current from the Christchurch Tramways need not be considered, as the Council could not supply what would be wanted without installing extra plant for the purpose; and, this being necessary, it would be more satisfactory for the Railway Department to install its own.

If electrification of this line were adopted, an acceleration of the speed would naturally be expected, and, as the starting and stopping of a train worked by electricity is quicker than with one worked by steam, no difficulty would be experienced in providing this.

The traffic on the Lyttelton–Christchurch line for the year ending 31st March, 1907, was as follows:—

Goods.

Number of tons moved (approximately only)	542,950
Number of tons moved per working-day	1,735

Passengers.

Number carried (approximately only)	1,340,000
Average carried per day (seven days per week)	3,671
Number of trains run each day	36

The following tables A and B show two methods of calculating the electrical energy required for the estimated train-services to be provided.

They have been prepared on a journey-time of fifteen minutes for a stopping passenger-train between Christchurch and Lyttelton, and ten minutes for a through train. The times of the goods-train will remain as at present.

The average speeds are, passenger-trains, thirty miles per hour; goods-trains, thirteen miles per hour.

A. *Table showing Electrical Energy required on the Basis of a Ton-mile Calculation.*

Trains.	Number of Trains per Day.	Average Weight of Trains in Tons.	Tonnage per Day.	Tonnage per Annum.	Total.
Passenger	36	112	4,032	1,262,016	...
" Sundays ...	13	112	1,456	75,712	...
Goods	19	320	6,080	1,903,040	
					3,240,768
Specials (add about 5 per cent.)	...	...	...	...	159,232
Total	...	...	...	...	3,400,000

Total Tonnage.	Length of Line, Miles.	Ton-miles.	Electrical Energy consumed.	
			Watt-hours per Ton-mile.	Kilowatts per Annum.
3,400,000	6·5	22,119,500	82	1,812,200

B. *Table showing Electrical Energy required on the Basis of Speed of Trains and Horse-power.*

Trains.	Average Weight: Tons.	Average Speed: Miles per Hour.	Average Estimated Horse-power.	Coefficient of Energy for Starting.	Horse-power Total.	Average Electric Kilowatts required per Train.	Trains per Annum.	Electric Kilowatts, Total.
Passenger ...	112	30	268	3	804	75	11,944	895,800
Goods	320	13	352	3	1,056	150	5,947	892,050
								1,787,850
Add for special trains 5 per cent.	...	...	...	...	...	...	...	89,392
Total ...	...	...	...	...	...	...	...	1,877,242

Estimated Cost of Installation.

(*a.*) The estimated amount of current required would therefore be 1,900,000 units. To supply this energy and to meet the maximum possible load with two goods and one passenger trains on both up and down roads at the same time, a 3,000-kilowatt plant would be wanted, together with a 1,000-ampere-hour booster battery with necessary duplicate parts, including buildings.

(*b.*) To run the goods service five electric locomotives would be necessary, four in regular use and one for emergencies.

The electric locomotive would also be used to run the Dunedin express or special trains of ordinary carriages between Christchurch and Lyttelton.

(*c.*) To run the ordinary passenger service, allowance has been made for three- and five-car trains made up as follows:—

Motor-cars, with compartment for guard and luggage, at each end of train, with one first, one second, and first and second composite smoking trailing cars between. The cost of these trains would be almost £8,000 each—£2,500 each for the motor-cars and £1,000 for the trailers.

(*d.*) The Lyttelton Tunnel would require the adoption of special methods for overhead equipment; but a fair estimate to allow for the whole section would be £5,000 per mile of double track.

The cost of installing electric traction would therefore be about as follows:—

	£
(*a.*) Power plant	60,000
(*b.*) Electric locomotives for goods traffic: five, at £3,500 each ...	17,500
(*c.*) Three passenger-trains at £8,000 each	24,000
(*d.*) Overhead equipment, 6½ miles, at £5,000	32,500
	134,000
Contingencies, 10 per cent.	13,400
Total	147,400

This for total equipment is equal to £11,338 per mile of single track.

The cost of the power plant appears high; but the maximum load—which would probably be only required a few times a day and only for a few minutes on each occasion—has to be provided for: the maximum load will be at least three times the normal. The power plant which it is necessary to provide would be capable of dealing with a very much larger traffic at proportionately only a small increased annual cost by running a continuous service, which of course can only be sustained where there is a heavy and regular suburban passenger traffic to deal with.

It is almost exclusively to this class of traffic that the application of electric traction on existing railways has so far been adopted; and, when all charges, including interest and depreciation, on the electrical installation are taken into account, the cost per ton-mile has in most cases been found to be higher than for a steam traction.

The net cost of generating electric current with an up-to-date steam plant, with cost of coal at about £1 5s. per ton, if power-house is erected at Lyttelton in such a position that the coal can be unloaded direct from the steamer to power-house bins, would be about 1d. per unit, and another ¾d. per unit should cover all distribution and general maintenance charges.

The annual charges on the basis of existing traffic would be about as follows:—

	£
Interest and depreciation on capital cost, £147,400 at 7½ per cent., say	11,055
Cost of generating current and general maintenance, 1,900,000 units at 1¾d., say	13,854
Total	24,909

As an alternative proposal, instead of supplying new passenger-trains the existing stock could be used, drawn by electric locomotives—say, three at £3,000 each: this would reduce the capital cost by £15,000, and the annual charges by £1,125.

Train-mileages.—The train-mileages for the service upon which the calculations are based would be about 118,000 per annum, and the annual charges for steam traction would be—locomotive charges, 17·36d.; other charges, 45·62d.; or a total of 62·98d. per train-mile.

For electric traction, equivalent locomotive charges, including supplying electric current and maintenance of plant, would be 31·30d.; other charges, 45·62d.; or a total of 76·92d. per train-mile, to which should be added interest and depreciation on cost of electrification, 22·48d. per train-mile, or 20·19d. for the alternative proposal.

	d.
Total cost steam traction	62·98
Total cost electric traction	99·40
Total cost alternative proposal	97·11

Extra cost under electric traction, 36·42d., or 34·13d. per train-mile: 118,000 train-miles at 36·42d. = £17,906 10s. So that the cost of working electrically will exceed the present cost by about £18,000 per annum.

The electrification of main lines of railways for dealing with both passenger and heavy goods traffic is at present practically only in an experimental stage, but from experiments now being carried out experts are of opinion that a considerable reduction will be effected both in initial and working costs in the near future.

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