RAILROAD ELECTRIFICATION
AS APPLIED TO A HELPER ENGINE DISTRICT.

by

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A thesis submitted to the Department of Mechanical Engineering and the Faculty of the Graduate School in partial fulfillment of the requirements for the degree of Mechanical Engineer.

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A THESIS SUBMITTED TO THE FACULTY OF
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PREFACE.

During the last few years the subject of electrification of our steam railroads has been treated very ably from many angles. For instance, several very valuable papers have appeared in technical journals and proceedings of engineering societies by men such as W. S. Murray of the New York, New Haven and Hartford Railroad, who are in close touch with operating conditions of electrified railroads. Others have appeared by men such as A. H. Armstrong of the General Electric Company, who are in touch with the manufacture of apparatus for electrification. Still others there are by such men as Charles P. Kahler of the Oregon Short Line Railroad, who are studying the operation of their companies' lines to predetermine the effects of the substitution of electrical motive power on operating expenses.

While these papers are of great value to the engineering profession, it is felt that there is a place in the literature pertaining to this subject for a paper pointing out as definitely as possible the lines of study and practice which will best fit a man to cope with problems in electrification. This has been the object of the author in this thesis. It has not always been the aim to obtain this by a definite statement but often by calling attention to the fact that certain decisions were made possible only after considerable study along certain lines which seem perhaps to the average electrical engineer to be unimportant or irrelevant.

In the final review of this thesis the author was aided in revising his manuscript by Mr. Charles P. Kahler and he desires to express appreciation for this assistance.

Thomas A. Purton.

Salt Lake City,
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INTRODUCTION:

The objects which it is desired to present in this paper are, in general, two in number.

First, it is intended to point out the kind of training which it is necessary for one to obtain who hopes to solve the great electrification problems which must come before railway officials in the near future.

Second, by means of a detailed analysis of the probable effects of the substitution of electrical power for steam power on part of a railway engine district, a method of approaching or attacking a problem of trunk line electrification is illustrated.

NECESSITY OF STUDY OF PAST DEVELOPMENT:

It is essential for the engineer or railroad official who is investigating any proposed improvement to base his decisions not only on the present development of the traffic and equipment of his company, but to plan the improvement to fit in with the future development which is to come. The basis for any estimate on future development must, however, be a study of past experience. A brief review will consequently be made at this point over the past development of the railroads of this country.

The development of the American steam railway system is a tremendous achievement of which we have a right to be justly proud. It has occurred along three general lines, viz.:

(a) Roadway.
(b) Traffic.
(c) Motive Power and Rolling Stock.

ROADWAY:

With the first of these subjects, Roadway, the electrical engineer or the engineer beginning the study of electrification, is perhaps inclined to think he is least concerned. However, as will be shown later, the knowledge of and experience with the subjects of grades, curvature, track and bridge strength, besides innumerable others, are absolutely essential to an intelligent study of electrification. The improvement in the roadbed of railroads since the early pioneer days of 1830 has been very great. In those days, cast iron, iron strap on wooden stringers, or even wooden stringers alone, were used for track. By the year 1880, however, there was one mile of road for about every 500 people and the heavy material which was being carried necessitated fairly good rails, bridges and track. A few steel rails had been laid as early as 1864. From 1880 to 1890 the expansion of the railways was tremendous and the mileage practically doubled.

The year 1890 marks a new era in development because the country being fairly well supplied with railroads at that time, construction slowed down. The panic of 1893 forced the railroads to rigidly economize and consequently from 1890 on to the present has been a time of development of the finer details of roadbed construction rather than rough laying of vast mileage. In view of the above, it is probable that no radical development in roadbed construction will occur in the near future.

Some of the most important of these later improvements are outlined below:

A great deal of study has been spent on the matter of track, drainage, proper ballast section, and the quality of ballast. This matter of ballast has an important bearing upon the methods of handling heavy freight trains, especially on steep grades, either by steam or electric power locomotives, as it has been found that if too heavy a proportion of the motive power is placed behind a train it is difficult for ballast to hold the track in place against the push upon it.

Probably the most important considerations of roadway which enter into the electrification problem or the handling of traffic by any kind of motive power, are the matters of ruling grade and rise and fall of the line or, in other words, the physical characteristics. The matter of defining ruling grade is a difficult matter for the reason that the limiting of the maximum train weight is influenced by such matters as starting grades and momentum grades. If ten miles is considered as the minimum speed at which a train will be allowed to run, except at starting and stopping, there is always some grade (sometimes actual, sometimes theoretical) which limits the tonnage of the train. A train loaded to run up a long grade of this degree would never get down below a minimum speed of 10 miles per hour at any point on the section and could be started at any starting grade. This grade is the ruling grade. The ruling grade of a district is that which limits the tonnage of freight trains. The loading of freight trains has a very great effect on operating expense. The ruling grade for electric locomotive is not always the same as for steam locomotive on the same district, on account of the difference in the tractive effort curves of the two types of locomotives. Therefore, a careful study of the profiles and alignment maps of a line, together with the tractive effort curves of the two types of locomotives, is the first step in an analysis of electrical operation.

TRAFFIC:

The development in the traffic of the railroads of America has far exceeded that in any other country. Up to about 1840 the railways were unable to compete successfully with the canal system which had been developed in the United States. For the next decade they acted merely as feeders to the water traffic. Not until 1860 did the railroads exceed the water traffic. At that time the total annual eastbound tonnage of the Pennsylvania was 350,000 and westbound it was 190,000 tons, or less than 1000 tons a day each way. Today our western roads carry from 8,000 to 16,000 tons every day each way. The complications in traffic development introduced by the Panama Canal and other trade conditions make the estimating of future traffic a problem worthy of the shrewdest railway man. Nevertheless it is one which is vital to the electrification expert. It is easy to see that cases must exist where the traffic of ten years ago would not warrant the introduction of electricity for motive power but in which perhaps great savings could be made by its introduction with present traffic, or as it will exist in five or ten years from now.

MOTIVE POWER:

The development of motive power for both steam and electric trains has called forth the highest talent and mechanical genius of our country. The modern steam locomotive is a wonderful production and its value should not be underestimated by electrical engineers but should be carefully studied to recognize its strength as well as its weakness. The recent development of the standard American types of steam locomotives for heavy freight service will be briefly outlined to show the lines along which improvement has occurred and what has been done in a very few years toward solving the same problem which electrification is now attempting to solve.

The standard locomotive for handling freight trains for a number of years has been the Consolidation or 2 - 8 - 0 type. During the last four years a new type, the Mikado, has grown out of the Consolidation. Two trailing wheels were added to certain consolidations used for pusher engines to enable them to back down the grades easily without derailments.

At first the firebox remained over the rear drivers as in the consolidation type. It was soon seen, however, that the additional two trailing wheels might be used to support the firebox, thus allowing an increase in size and depth of that important part, and this has increased the capacity of the Mikado very materially over the Consolidation. This Mikado type is now used by a number of railroads to handle their heavier freight trains and it is used by the Union Pacific System for handling some heavy passenger trains.

Another type which has been developed and which has an important bearing on electrification, is the Mallet articulated compound, which was originally built after the idea of a Frenchman named M. A. Mallet. The Mallet engine in its earlier forms has four cylinders, two high pressure and two low pressure. The driving wheels are divided up into two sets, the two sets being connected by an articulated joint. The boiler reaches over both sets and either has a flexible joint in its middle or else flexible steam pipe connections to the cylinders. The heaviest Mallet up to the year 1914 was the Santa Fe 2 - 10 - 10 - 2 engine with a total weight of engine and loaded tender of 850,000 pounds. During 1914, however, the Baldwin Locomotive Works built a locomotive for the Erie Railroad which surpasses anything yet seen. This is called the Triplex Compound or Centipede type, its wheels being laid out as 2 - 8 - 8 - 8 - 2. It has two high pressure cylinders and four low pressure cylinders. One set of cylinders and drive wheels are under the tender. The following table gives the desdriptive data of this locomotive:

TABLE I.

ERIE MALLET TRIPLEX LOCOMOTIVE - DESCRIPTIVE DATA.

Service..................................	Pusher.
Fuel.....................................	Bituminous coal.
Tractive effort, compound................	160,000 lbs.
Total weight on drivers..................	761,600 lbs.
Total weight of engine and tender........	853,050 lbs.
Diameter of drivers......................	63 inches.
Steam pressure in boiler.................	210 lbs.
Total heating surface (Excluding superheater)	6,886 sq.ft.
Grate area...............................	90 sq.ft.
Water Capacity...........................	10,000 gals.
Coal capacity............................	16 tons.

This new locomotive is to be used for pusher service on an eight mile section of line averaging 1.06% grade. Full tonnage trains were previously brought up the hill by one consolidation in front and with two consolidation and one Mallet pushing. This new triplex or centipede type was produced to take the place of all three of these pushers. This new locomotive has practically all the auxiliaries which the modern power house has in its boiler room to increase efficiency, such as combustion chamber, mechanical stoker, feed water heater, feed water pumps, superheater, and

Eighty-nine percent of the total weight of the engine and tender is on the drive wheels, which is remarkable for steam practice.

When such a development as this takes place in steam locomotive practice in such a small space of time it is well for the electrical engineer to consider carefully this machine, which he proposes to replace, to see what the factors are, if such exist, which limit further important development in steam motive power. Such limiting factors do exist, and some of the most important are as follows:

(1) Gauge of track and clearances.
(2) Boiler capacity and firing capacity.
(3) Concentrated weight on the drivers.
(4) Cost of coal.

These will be taken up in the order given above:

(1) The standard gauge of track in the United States is four feet and eight and one half inches. To increase the gauge would, of course, require an enormous amount of capital.

As the gauge now exists and with present clearances of bridges, tunnels, and buildings, it is practically impossible to increase the size of a locomotive in breadth or height and the only direction left for expansion is in length. The latest types of locomotives have therefore increased greatly in length.

(2) The steaming capacity of the boiler is reallytthe limiting factor in steam locomotive development. As stated above, no expansion is possible in breadth or height of boiler and extremely long boilers are inefficient. Also it has been found impossible for the fireman to throw coal fast enough to keep steam up in the latest designs as about 5,000 pounds of coal an hour is the capacity of the ordinary man. Mechanical stokers have been introduced but they introduee complexity, which has been considered very undesirable.

(3) Strength of bridges and track limit the concentrated weight on one pair of drivers to from 55,000 to 65,000 lbs.

(4) The cost of coal is rapidly going up, which tends to counteract the benefit of development of efficiency in steam locomotives.

ELECTRICITY FOR MOTIVE POWER:

Within the last fifteen years the field of the steam locomotive on trunk lines has been seriously invaded by a new type of motive power, - the electrically driven locomotive and motor car.

The first railroad to use electric motive power for handling heavy traffic in serious competition with steam locomotives was the Baltimore and Ohio, which began its use to alleviate smoke troubles in the Baltimore Belt Tunnel in 1895. Since that date, a number of installations of electric locomotives have been made on various roads to accomplish the same results in their tunnels. Instances of this have been the Hoosac Tunnel of the Boston & Maine Railroad, and the Cascade Tunnel on the Great Northern, as well as the Pennsylvania Tunnel leading into New York City.

While the earlier substitutions of electricity for steam were made with the object of overcoming special disadvantages experienced with steam locomotives, the railroads now realize that in the matter of economy and saving in operating expenses, electricity will become a very large factor. Also it has been found that by the substitution of electricity the capacity of a greatly congested portion of line can be considerably increased and this may save a heavy investment of capital in grade reduction or in double track, or perhaps in the entire rearrangement of terminals.

SYSTEM OF ELECTRIFICATION:

The development of electrification has produced several distinct systems, which may be classified as follows:

(a) Direct current of 600, 1200, 1500, 2400 and 3000 volts.
(b) Three-phase alternating current of voltage up to 6600.
(c) Single-phase alternating of voltage up to 15,000.
(d) Modifications of these three systems.

Each of these systems has a number of advantages and a careful study of the conditions existing on the particular line in question is necessary to determine which system is most applicable to fit the problem.

A number of successful installations have been made with each of the systems and in comparison with the large question before the railroads of the country of steam or electric drive this question of choice of system is a minor matter.

Considering the electric locomotive as compared with steam, there are certain important points which are critically studied and examined by the railroad man and these will be briefly examined.

(a) Reliability:

The first of these is its reliability. Can the electric locomotive be depended upon to handle the heavy trains in regular service in all kinds of weather as well as steam locomotives? This question may be answered by reference to the records of two of the important electrified trunk lines which have been in operation some time. The New York, New Haven and Hartford, during 1910, had only two-thirds as many electric locomotives failures per train mile as it had with its steam locomotives. The recently published comparative records of the Butte, Anaconda & Pacific Railroad show that during the month of June, 1913, while the traffic was being handled by steam motive power, the delays due to locomotive failures totaled 44 minutes; while in June, 1914, after electric locomotives had been installed, the delays due to this cause totaled but 24 minutes.

While extremely cold weather has a great tendency to stall a steam locomotive on account of the radiation from its boiler, the cold itself is an aid to the electric locomotive in keeping its motors cool.

Capacity;

The most important consideration is the capacity of the locomotive. In this respect the electric locomotive has a tremendous advantage over the steam locomotive. With the former practically all the weight is on the drivers, the coefficient of adhesion is greater, an unlimited supply of power is available without depending upon the steaming capacity of a portable boiler or the firing capacity of one man. Also the characteristics curves of the electric locomotive have a more advantageous shape than those of the steam locomotive. An examination of Figure 1 shows this advantage in curve shape. At high speeds the steam locomotive is seen to have greater tractive efforts than the electric locomotive. At lower speeds, however, the electric locomotive has much the greater tractive effort. This means that by dropping down to low speeds the electric locomotive can handle heavy loads that will stall the steam locomotive.

Simplicity:

Besides the matters of reliability and capacity, the electric locomotive is much simpler than the steam locomotive, requires much less time to properly inspect and handle it at a terminal, costs much less for repairs, does not start fires along the right of way and gives no chance for internal explosions.

INCREASE IN REVENUE:

On the other hand, it has been found that with the introduction of electricity on railroads the increase in revenue, especially in local passenger accounts, has been very marked in many cases. This is due to the increased number of trains possible, cleanliness, the absence of cinders, the easy and speedy handling of trains and the increased number of stops made possible.

ANALYSIS OF AN ELECTRIFICATION PROBLEM.

Description of Line Considered:

It is now intended to take up a special problem in railway electrification and trace the analysis through from certain bases to the results and conclusions.

The section of line which will be considered in this discussion is part of an engine district of a western railroad which includes a helper grade or a grade upon which it is necessary to use from two to four engines to operate trains which are loaded to be hauled over the rest of the district by one engine.

The country through which the line runs is a not very thickly populated land, most of the towns and settled districts being on reclaimed desert land. However, the line is part of one of the most important transcontinental trunk railroads and has first class ballast roadbed and track and an excellent system of automatic block signals.

The section to be considered is 85 miles long, between Terminal No. 1 and Terminal No. 2, and the helper grade on the present operated line is 9 miles long.

Proposed Line Change:

On account of the heavy expense which is required to operate the helper grade and on account of the congested traffic conditions caused in part by the light helper engines returning from the top of the grade, it has been proposed to make a change in the helper district with a resulting reduction in grade. This change in line would reduce the total length over the section considered from 85 miles to 83.1 miles. The grade is reduced on the helper grade from a maximum of 2% to a maximum of 1% grade.

Grade Reduction:

The proposed new line is 13.25 miles long and connects with the old line at Mile Post 5 and reconnects with the old line at Mile Post 18.1, thus reducing the mileage by 1.85 miles. It has a uniform grade of 1% throughout its length.

A careful study of the effects of this change on the operation of the line shows considerable reduction in train miles and locomotive miles. The important basis for this reduction in mileage by the reduction of grade is the fact that this particular helper grade is the ruling grade of the engine district and on this account any reduction of this grade results in heavier allowable tonnages on the freight trains. This in turn cuts down the number of freight trains required to handle the traffic. The operating expenses of trains and engines is to a large degree in direct proportion to their mileage so that a great saving results. A reduction in fuel cost also results.

The estimated cost of the reduction in grade has been placed at $1,500,000.00. Since the actual estimating of such a change of line is a matter not directly connected with the objects of this paper, no analysis of the estimate will be made here. However, the resulting reduction of operating expenses is carefully analyzed below.

The effect of this reduction will also be to relieve considerably the congestion of the line, since the train miles are so materially reduced and greater speed can be maintained up the grade. Also the reduction of grade from 2% to 1% tends to increase very materially the safety of trains coming down the grade.

Electrification of the District:

The above mentioned advantages gained by the reduction of grade would also, with the exception of the last, be gained if electrically driven helpers were introduced for use on the present grade of 2%. The reason for this lies in the more advantageous tractive effort curves of the electric locomotive over the curves of the steam locomotive. This effect, as mentioned above, is illustrated in Drawing No. 1, which shows that at the comparatively low speeds at which the hill is operated the electric locomotive has a great advantage in tractive effort. Consequently, an increase in freight train weight over the district would be possible with the consequent reduction in train miles, locomotive miles and operating expenses.

System of Electrification:

In this study of electrification it is necessary that some particular type of electrical equipment be considered, since the characteristics, power requirements and costs would vary to some extent for the particular piece with the use of direct current, single phase or three phase equipment. Although in a large measure the results of electrification would be the same with some other type of electric locomotive, it is considered that the single phase series motor equipment used with 11,000 volt, 15 cycle current on the trolley would probably work out to best advantage for the ultimate electrification of the entire district. Consequently it is considered in the analysis of this short section.

Power Necessary:

The power necessary for this project is considered as purchased from a nearby power company at the rate of 0.75 cent per kilowatt hour. It might be found upon careful working out of all phases of this problem that a power station owned and operated by the railroad company would be advantageous rather than purchasing power. However, that is a problem in itself, upon which a great deal of time and study would have to be spent, and it has no direct bearing upon the case we are considering as far as the preliminary analysis is concerned.

Type of Electric Locomotive:

The locomotive which will be considered is of 110 tons total weight, with all the weight on the four sets of drivers. Four of these locomotives will be required, and for full tonnage freight trains two of these locomotives, operated by multiple control as one unit, will be needed on the hill. The reason for taking this size of locomotive is that this type works in with plans for ultimate electrification of the entire district. For the hill alone, lighter locomotives would probably balance up better with the single steam locomotive on the rest of the district.

Substation:

One substation is necessary for transforming down the high voltage power from the power company's lines. The power will be purchased at the substation as 15 cycle current, so that frequency changers will be unnecessary. The substation will be of 4000 K.V.A. capacity.

Cost of Electrification:

The cost of the electrification is estimated to be $370,000.00. The details of this estimate are shown in Table II.

TABLE II.

Estimated Cost of Electrification of Helper Grade.

Item.	Quantity.	Rate.	Amount.	Total.
Track Bonding	21 mi.	$450.	$9450.00	$9450.00
Overhead Construction:				
Pole & Bracket Lines (Incl.Yards & Sidings)	21 mi.	1900.	39900.00	
Section Breaks			2000.00	
Additional for Curves			500.00	40600.00
Trolley & Messenger:				
3/0 Grooved trolley	21 mi.	700.	14700.00	14700.00
Substation, 4000 KVA	1	48000.	- -	48000.00
Rolling Stock:				
Locomotives	4	50000.	200000.00	200000.00
Changing Block Signals: & Telegraph:	25 mi.	1500.	37500.00	37500.00
Additions to Shops:			- -	5000.00
Engineering & Supervision:	5%		- -	17762.00
Contingencies			- -	36988.00
		Total, ...		410000.00
Steam Engines Released:	4	10000.	40000.00	40000.00
		Net Investment, ...		$370000.00

Comparative Analysis:

Analyses will now be made of the operating expenses of the three above outlined methods of operating this section of line. The first of these uses steam helping locomotives on the present 2% helper grade. The second uses steam helpers on the line changed to a 1% maximum grade. The third uses electric helpers on the present 2% grade. These operating costs will be compared and the most advantageous method pointed out.

Method of Analysis:

It is customary at present for the railroads in their accounting to follow the prescribed classification of accounts of the Interstate Commerce Commission. The strict adherence to these classifications in a comparison such as that contained in this paper would result in complications as a large number of items of expense which are accrued on this section of line are exactly the same whether the operation is by steam or electric motive power, or whether the grade is 1% or 2% maximum. Consequently, an arbitrary classification of accounts has been assumed which it is thought will bring out to best advantage the comparison desired and will at the same time not introduce any accounts which are not materially affected by change of method of operation. At the same time, the Interstate Commerce Commission classification will be used as a general guide.

The comparison will, therefore, be made on the following three general accounts:

I. Maintenance of Way and Structures.
II. Maintenance of Equipment.
III. Conducting Transportation.

These general accounts are subdivided into a number of primary accounts, as shown in Tables VI, VII and VIII.

Basis of Operating Expense Figures:

The figures given in the various tables are practically all worked up on a pro rata plan from the statistics of the present operated line. The base figures for these tables were obtained in the following way: A table similar to Table V was made for the entire division of which this section is a part. This was made up from the daily reports of conductors and train dispatchers. This table, together with the total known expense of each item, gave the unit rate for each item, which was applied in the tables for different methods of operation. Of course, judgment must be exercised in the application of these rates, as well as in the use of special rates for electrical operation.

Present Traffic:

The passenger traffic over this line consists of an average of 4.2 passenger trains each way per day. For these analyses the following freight tonnages will be assumed:

TABLE III A.

Assumed Annual Freight Tonnage.

Class of Freight.	Annual Tonnage of Cars and Contents Westbound.	Annual Tonnage of Cars and Contents Eastbound.
Expedite Freight	880,000	660,000
Drag Freight	1,870,000	1,430,000
Local Freight	220,000	110,000
Total	2,970,000	2,200,000

NOTE:-Figures for total tonnage for an investigation of this kind can be obtained from the operated railroad company's Auditor, or for a new line they may be estimated from roads in a similar or the same locality. They form the basis for the whole analysis of the operating expenses of freight trains.

Number of Freight Trains Required:

Determination of the number of freight trains is the next step. It is very important in the handling of freight traffic that the number of freight trains be kept down to the minimum, since train miles are an important factor in a very large number of the items of operating expense. In order to calculate the number of trains for this section of line, it is necessary to study the profile and grades, together with the tractive effort curve of the locomotives to be used.

A profile of the section of line is shown in Drawing 2. By a study of this profile and by computing velocity curves for the heaviest freight trains it is found to be possible to carry with present steam locomotive equipment, using one engine over the district and with two helpers on the hill, a load of 2040 tons (1855 tons trailing) westward and 2240 tons (2055 tons trailing) eastward, with a minimum speed of ten miles per hour. The limiting or ruling grade westbound is found to be the helper grade and is equivalent to 0.62% over the entire section.

Having now the maximum weight of freight train it is simple to calculate the number of freight trains. It is necessary, however, to introduce a factor at this point to obtain the average weight of freight from the maximum. It is obviously impossible, on account of difficulties of making up trains and dispatching, to load every train to the maximum. Eighty percent of the maximum loading for the average weight of freight trains has been found to be a good figure and will be used.

By the same method as used above, the maximum and average weight of freight trains with electric locomotives is found and also with steam helpers on the reduced grade of 1%.

TABLE III B.

Table of Average Train Weights
Trailing Tonnage.

Class.	Present Line West	Present Line East	1% Grade West	1% Grade East	Electric Helpers West	Electric Helpers East
Expedite Freight	1172	1556	1426	1556	1426	1556
Drag Freight	1484	1644	1732	1644	1732	1644

It is to be noted in the above table that with the reduction of grade or the introduction of electric helpers the helper grade ceases to rule the tonnage over the district but this is ruled by a grade of 0.52 westbound.

From these average weights of trains the total annual number of trains is calculated from Table III A.

Expedite trains must be run at a higher speed and, consequently, instead of figuring them at a minimum of ten miles per hour they are figured at a minimum speed of fifteen miles per hour. This decreases the average train weight for this class of freight, with a consequent increase of number of trains.

Table IV shows the number of trains per year calculated on this basis.

TABLE IV.

Class of Freight	Total Annual Number of Trains: Present Operation West	Present Operation East	1% Grade on Hill West	1% Grade on Hill East	2% Grade with Elec. Helper. West	2% Grade with Elec. Helper. East
Expedite Freight	750	424	617	424	617	424
Drag Freight	1260	869	1079	869	1079	869
Local Freight	182	183	182	183	182	183
Total	2192	1476	1878	1476	1878	1476

Since the total number of trains in each direction must be the same, the number of eastbound trains will have to be raised to equal the westbound, as for instance, in present operation the total number of freights each way must be 2192.

Using Table IV and the known distances of the section of line and of the helper grade, Table V of train miles, ton miles, and locomotive miles is now calculated and shown below.

TABLE V.

	Present Operation.	1% Grade, Steam Helpers.	2% Grade, Electric Helpers.
Trains per Day:			
Passenger	8.4	8.4	8.4
Freight	12.0	10.2	10.2
Train Miles:			
Passenger Trains	260,610	255,449	260,610
Freight Trains	372,300	309,381	316,455
Total	632,910	564,830	577,065
Locomotive Miles:			
Passenger Locomotives	263,200	258,000	263,200
Freight Locomotives	376,000	312,500	319,600
Helper Locomotives	150,000	50,000	130,000
Total	789,200	620,500	673,900
Ton Mileage:			
Passenger Trains	164,653,380	161,392,590	164,653,380
Freight Trains	509,010,000	497,262,000	498,576,000
Helper	27,750,000	9,250,000	14,300,000
Total	701,413,380	667,904,590	677,529,380
Distance	85	83.1	85

From Table V and from basic rates obtained as explained on Page 13, Tables VI, VII and VIII are drawn up and the results summarized in Table IX.

TABLE VI.
Maintenance of Way and Structures.

Item.	Base: Present Operation.	Base: 1% Grade Steam Helpers.	Base: 2% Grade Electric Helpers.	Rate.	Amount: Present Operation.	Amount: 1% Grade Steam Helpers.	Amount: 2% Grade Electric Helpers.
Superintendence	632910	564830	577065	$.00742 per tr.mi.	$4696.19	$4191.04	$4281.82
Ballast & Ties	701413380	667904590	677529380	.00007046 " ton "	49421.59	47060.55	47034.12
Rails & Other Track Matl.	701413380	667904590	677529380	.00001437 " " "	10079.31	9597.78	9736.09
Applying Ballast, Ties, Tie Plates	701413380	667904590	677529380	.0000138 " " "	9679.50	9217.08	9349.90
Applying Rails & Fastenings	701413380	667904590	677529380	.0000078 " " "	5471.02	5209.65	5253.52
Maintenance & care of Trk.	701413380	667904590	677529380	.0000553 " " "	38788.15	36935.12	37246.17
Maintenance & care of Roadbed	85 mi.	83.1 mi.	85 mi.	156.14 per mi.	13271.90	12975.23	13271.90
Bridges	85 "	83.1 "	85 "	32.79 " "	2787.15	2724.84	2787.15
Signs,etc.	85 "	83.1 "	85 "	42.02 " "	3571.70	3491.86	3571.70
Signals	85 "	83.1 "	85 "	45.40 " "	3859.00	3772.74	3859.00
Telegraph	85 "	83.1 "	85 "	18.40 " "	1564.00	1529.04	1564.00
Roadway & Station Bldgs.	85 "	83.1 "	85 "	89.54 " "	7610.90	7440.77	7610.90
Enginehouses & Shops	100%	100%	90%		7787.64	7787.64	7008.87
Fuel Stations	100%	100%	95%		2406.35	2406.35	2286.03
Water Stations	100%	100%	100%		3244.45	3244.45	3244.45
Roadway Tools & Supplies	701413380	667904590	677529380	.00000746 per ton mi.	5232.54	4982.56	5024.52
Injuries to Persons	632910	564830	577065	.00007 per tr.mi.	44.30	39.53	40.39
Maintenance of Electric Lines:							
Poles & Fixtures	00	0	20 mi.	$500 per mi.	0.00	0.00	1000.00
Distribution System	0	0	20 mi.	20. " "	0.00	0.00	400.00
Substations	0	0	$48,000.	1/2%	0.00	0.00	240.00
Depreciation of Electric Lines:							
Poles & Fixtures	0	0	$35,350.	5%	0.00	0.00	1767.50
Distribution System	0	0	$23,100.	4%	0.00	0.00	924.00
Substations	0	0	$48,000.	3%	0.00	0.00	1440.00
All Other Accounts	100%	100%	100%		15484.31	15493.77	15457.97
Total					$185,000.00	$178,100.00	$184,400.00

TABLE VII.

Maintenance of Equipment

Account.	Base: Present Operation.	Base: 1% Grade Steam Helpers.	Base: 2% Grade Electric Helpers.	Rate.	Amount: Present Operation.	Amount: 1% Grade Steam Helpers.	Amount: 2% Grade Electric Helpers.
Superintendence	632910	564830	577065	$.00184 per tr.mi.	$1164.55	$1039.28	$1061.80
Locomotive Repairs:							
Passenger	263200	258000	263200	.1104 per loco.Mi.	29057.28	28483.20	29057.28
Freight	376000	312500	319600	.125 " " "	47000.00	39062.00	39950.00
Helper	150000	50000	130000	Steam .125, Elec. .05 per loco.Mi.	18750.00	6500.00	5192.70
Passenger Car Repairs	2345490	2293061	2345490	.01172 per car mi.	27489.14	26874.67	27489.14
Freight Car Repairs	11392380	11137727	11392380	.00602 " " "	68582.13	67049.12	68582.13
Shop Machinery & Tools	632980	564830	577065	.0058 per tr.mi.	3671.28	3276.01	3346.98
Coal Cars Repairs	1109760	832320	763640	.00602 " car "	6689.75	5010.56	4597.11
Depreciation:							
Freight Locomotives	274000 (15)	216000 (12)	216000 (12)	4%	10960.00	8640.00	8640.00
Helper "	72000 (4)	36000 (2)	200000 (4)	4% Elec. 3%	2880.00	1440.00	6000.00
Coal Cars	68000 (68)	51000 (51)	46000 (46)	4%	2755.87	2125.16	1882.86
Total					219000.00	189500.00	195800.00

TABLE VIII.
Transportation Expenses.

Item.	Base: Present Operation.	Base: 1% Grade Steam Helpers.	Base: 2% Grade Electric Helpers.	Rate.	Amount: Present Operation.	Amount: 1% Grade Steam Helpers.	Amount: 2% Grade Electric Helpers.
Superintendence	632910	564830	577065	$.0116 per tr.mi.	7341.75	6552.03	6693.95
Road Enginemen -							
Passenger	263200	258000	263200	.0814 " Loco."	21424.48	21001.20	21424.48
Freight	376000	312500	319600	.108 " " "	40608.00	33750.00	34516.80
Helper Enginemen	150000	50000	130000	.10 " " "	15000.00	5000.00	13000.00
Enginehouse Expenses	19	14	(12 Steam	1400 " Loco.)	26600.00	19600.00	18400.00
			(4 Elec.	400 " ")			
Fuel,passengerLoco.	17660	17315	17660	1.77 per ton.	31258.00	30647.55	31258.00
Fuel,freight "	45300	37650	38500	1.77 " "	80181.00	66640.50	68145.00
Fuel,helper "	18749	6250	0000	1.77 " "	33185.75	11062.50	0.00
Hauling Coal - Mines to terminal	81609	61215	56160	1.13 " "	92218.17	69172.95	63460.80
Water,Road Locomotives	632910	564830	577065	.01367 per tr.mi.	8651.87	7721.22	7888.49
Lubricants -							
Passenger Locomotives	263200	258000	263200	.27 ¢ per loco.mi.	710.64	696.60	710.64
Freight "	376000	312500	319600	.34¢ " " "	1278.40	1062.50	1086.64
Helper "	150000	50000	130000	.34¢ Steam .17¢ Electric,per loco.mi.	512.00	170.00	221.00
Other Supplies - Road Locomotives	100%	90%	90%		3229.95	2906.95	2906.95
Purchase of Electric power,K.W.hour	0	0	2250000	.0075 per kw.hr.	0.00	0.00	16875.00
Road Trainmen - Pass.	260610	255449	260610	.06866 per tr.mi.	17893.48	17539.13	17893.48
" " - Freight	372305	309381	316455	.13265 " " "	49386.26	41039.40	41977.75
All other Accounts	85	83.1	85	1577.66 per mi.	134120.25	131137.47	134141.02
Total					663600.00	466100.00	480600.00

TABLE IX.

GENERAL SUMMARY.

	Present Operation.	1% Grade Steam Helpers.	2% Grade Electric Helpers.
Maintenance of Way & Structures	$ 185,000.00	$ 178,100.00	$ 184,400.00
Maintenance of Equipment	219,000.00	189,500.00	195,800.00
Transportation Expenses	663,600.00	466,100.00	480,600.00
Totals	1,067,600.00	833,700.00	860,800.00
Capitalized at 5%	21,352,000.00	16,674,000.00	17,216,000.00
Cost of Construction	0.00	1,500,000.00	370,000.00
Totals	21,352,000.00	18,174,000.00	17,586,000.00
Credit for Coal Cars Released	0.00	17,000.00	22,000.00
Grand Total	21,352,000.00	18,157,000.00	17,564,000.00
Annual Operating Expenses, with 5% interest on Construction Costs,-	$ 1,067,600.00	$ 907,850.00	$ 878,200.00

CONCLUSIONS:

From Table IX it is found that while the expenditure of $1,500,000.00 on the reduction of the grade to a 1% maximum is a good financial investment, it is found that the expenditure of $370,000.00 for the electrification is still a better investment and is the plan that should be followed.

The above study brings out this most important fact relative to future electrification expenditures, that the handling of these tremendous expenditures of capital is not going to be intrusted to electrical manufacturers' agents but to engineers trained in all the intricacies of railroad operation and economics.

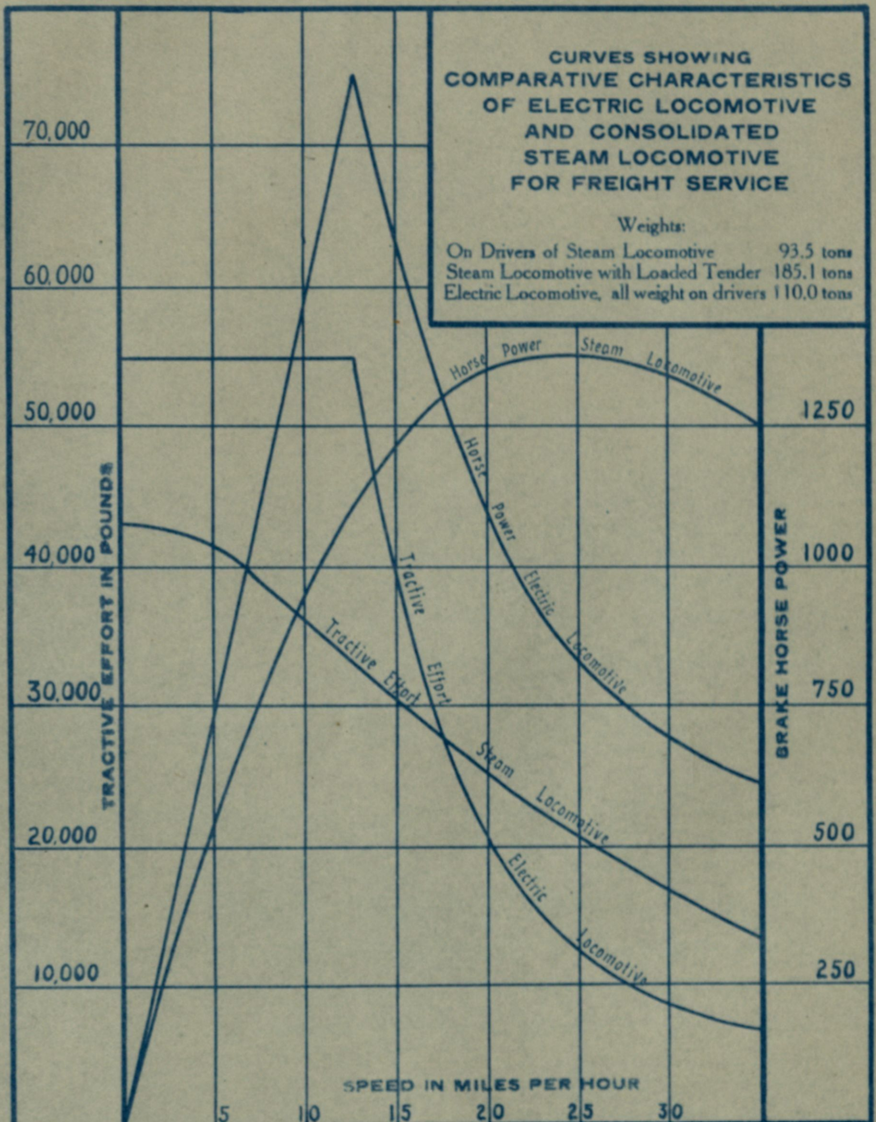
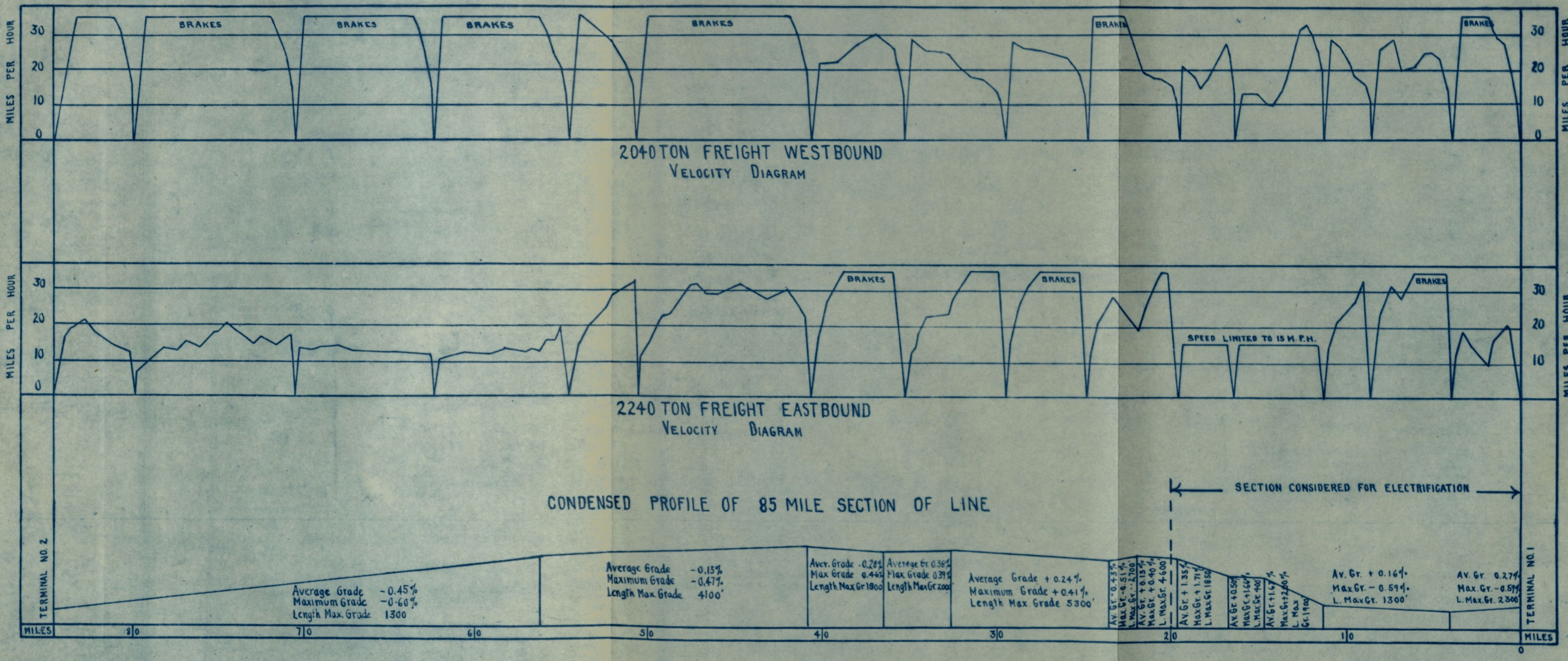

CURVES SHOWING
COMPARATIVE CHARACTERISTICS
OF ELECTRIC LOCOMOTIVE
AND CONSOLIDATED
STEAM LOCOMOTIVE
FOR FREIGHT SERVICE
Weights:
On Drivers of Steam Locomotive 93.5 tons
Steam Locomotive with Loaded Tender 185.1 tons
Electric Locomotive, all weight on drivers 110.0 tons
TRACTIVE EFFORT IN POUNDS
70,000
60,000
50,000
40,000
30,000
20,000
10,000
BRAKE HORSE POWER
1250
1000
750
500
250
SPEED IN MILES PER HOUR
5
10
15
20
25
30
Horse Power Steam Locomotive
Horse Power Electric Locomotive
Tractive Effort
Tractive Effort Steam Locomotive
Electric Locomotive

Fig. 1

FIGURE 2.



MILES PER HOUR
BRAKES
2040 TON FREIGHT WESTBOUND
VELOCITY DIAGRAM
SPEED LIMITED TO 15 M.P.H.
2240 TON FREIGHT EASTBOUND
VELOCITY DIAGRAM
SECTION CONSIDERED FOR ELECTRIFICATION
CONDENSED PROFILE OF 85 MILE SECTION OF LINE
TERMINAL NO. 2
Average Grade -0.45% Maximum Grade -0.60% Length Max. Grade 1300
Average Grade -0.13% Maximum Grade -0.47% Length Max. Grade 4100'
Aver. Grade -0.28% Max Grade 0.46% Length Max Gr 1900
Average Gr. 0.38% Max Grade 0.39% Length Max Gr. 2000
Average Grade + 0.24% Maximum Grade + 0.41% Length Max. Grade 5300'
Av. Gr. -0.43% Max. Gr. -0.51% L. Max. Gr. 2700'
Av. Gr. + 0.13% Max Gr. + 0.40% L. Max Gr. 4600
Av. Gr. + 1.35% Max Gr. + 1.71% L. Max Gr. 1850
Av. Gr. + 0.50% Max Gr. + 1.66% L. Max Gr. 400'
Av. Gr. + 1.67% Max. Gr. + 2.00% L. Max Gr. 1900'
Av. Gr. + 0.16% Max. Gr. - 0.59% L. Max Gr. 1300'
Av. Gr. 0.27% Max. Gr. - 0.59% L. Max. Gr. 2300'
TERMINAL NO. 1
MILES

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