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NOTES ON ELECTRIC TRACTION UNDER STEAM RAILWAY CONDITIONS.

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On many of the large steam railroad systems in the United States, there are certain sections which present the most favorable conditions for the substitution of electricity for steam as a motive power. These conditions are the result of increasing density of population, and mean that better and cheaper transportation facilities are needed by the public than are provided by the steam road.

The electric street railroads quickly took advantage of these conditions, and by building lines more or less parallel to the steam roads, soon acquired a large share of the local passenger traffic. The fault with the steam road was not that the motive power was steam, but the fare was too high and the train service too infrequent. The whole question of the substitution of electricity for steam hinges upon that one point.

In order to provide satisfactory transportation facilities, the steam road must double or quadruple the number of its trains, and reduce the fare to at most one cent per mile. When there is sufficient density of population, this will surely cause a large increase in the number of passengers carried. This increase is due principally to the fact that many people who could seldom afford the expense of traveling would then make frequent trips. It is very doubtful whether the greater number of steam trains can be operated at a sufficient profit with the low fare. Here, then, comes in the change in motive power, with the sole purpose of decreasing the operating expenses.

I wish to call attention to two classes of local passenger traffic which should be considered as distinct from each other. The suburban traffic of a large city is well understood, and its characteristics are usually such as would make the change from steam to electricity profitable. The low fare will induce a part of the population to make their homes in the suburbs, and thus increase the travel. But where there are competing trolley lines, the steam road, which we will suppose has electric motive power, needs one more facility than those mentioned, and that is, high speed. Without that, there would be little advantage over the competing lines.

It has been proved by experience that the speed must be at least as great as an average steam train, and there is no doubt that if the speed be made as high as the fastest steam express train, the popularity of the line would increase. It is well-known that the business man who desires to travel from one city to another, or to and from his residence and his place of business, cannot be carried there too rapidly. It would probably surprise the average passenger on one of the fast steam express trains to be told at a certain time that he was traveling 70 miles per hour, and yet such speeds are reached every day, for short distances, over a straight, level track.

The other class of traffic referred to is that existing between cities and towns in close proximity. Let us assume a case as an example.

In a certain densely populated manufacturing state, there is a city larger than any other within fifty miles radius. Within that radius are several towns and small cities not over twenty to thirty miles from the larger city. These are connected by the steam road, which maintains what is considered a reasonable train service, and one that is as frequent as the traffic seems to demand, at the rate of fare charged, which is from two to two and one-half cents per mile. The trains are quite heavy, nearly always fully loaded, and are run from two to three hours apart. Together with its freight traffic, such a road pays well, judged from the steam road's standpoint. Suppose that electricity be substituted for steam in that section, and a train service consisting of two, or three car trains running every half hour from each end, with a maximum speed of fifty to sixty miles per hour, and the fare reduced to one cent per mile. There is no doubt in the minds of those who have watched the development of such cases, that the increase in traffic and low operating expenses would result in a far greater profit than was ever earned by that section of the road. It is well-known that such conditions exist on our steam railroads in many localities.

It has been said that the steam roads will begin by equipping their branch lines with electric motive power, and little or nothing is heard of the equipment of the main trunk line. It is necessary to define what is meant by a branch. In a large system some branches are 100 miles long and may be double tracked; others are from six to forty or fifty miles in length. In the assumed case described above, the conditions may exist on one of the large branches or even on the main trunk line, which may have four tracks. It should make no difference in deciding the question of equipping the part of the system which possesses the desired conditions, whether it is on a branch or a part of the main line. It should be fully understood that no steam railroad will equip any portion of its lines, except with the provision that nothing shall be done which will prevent the running of steam and electric trains over the same track.

A well known authority, nearly five years ago, mentioned the possibility of the equipment of one or two of the tracks of a four-track trunk line by electricity, to carry the local traffic, and stated that the two tracks equipped should be those used by the freight trains. At the present day that does not seem advisable, for the reason that the speed of the electric trains must be equal to that of the steam express trains, and the slow moving freight trains would seriously interfere with the electric schedule. But it is unlikely that any steam road will equip a part of its main trunk line until it has satisfied itself, as to financial results, by giving it a thorough trial elsewhere.

The reduction of fares combined with the use of open cars during the hot summer months, produce a class of passengers which formerly used the electric street cars. These have been called the pleasure riders, and they furnish a considerable proportion of the receipts. Experience with open car trains has shown that speeds of 30 to 35 miles per hour are the maximum which should be used, on account of the discomfort caused by the wind pressure created by the train.

The Question of Equipment.

The questions, how much will it cost to equip a given service to be operated by electricity?—and how much will it cost to operate it? are frequently asked. The electrical engineer is now in a position to answer both these questions with great accuracy. The experimental stage has passed, and sufficient data is at hand to give all the information needed. It must be realized that the operation of a steam railway by electric power introduces many conditions which do not exist in the transportation problem within a great city, such as are operated by the elevated or surface street railroads. There are no restrictions on speed or weight of trains. Rapid acceleration is not of so much importance, for the stops are much further apart. The trains must be operated under steam rules absolutely, and the whole equipment must comply with the laws relating to steam railway trains. The railway company contemplating the equipment of a part of its system with electric motive power has the choice of several methods which should be closely studied to determine which is best suited for the service it is proposed to operate.

These methods are:

First: The purchase of electric locomotives of sufficient power and weight to haul its standard passenger coaches.

Second: The equipment of a number of its standard coaches as motor cars.

Third: The purchase or building of a sufficient number of special light passenger coaches, some of which are equipped as motor cars, and the withdrawal of its standard coaches entirely from this service.

Fourth: Shall freight be hauled by electricity or steam?

The use of electric locomotives for the purpose under consideration depends upon several conditions. If the travel is heavy, that is 2,000,000 passengers per year and upward, the service frequent, the speed high, requiring an average train of four cars, and, as may be the case, the same coaches must go much further than the electric service extends, hauled by steam, it is advisable to use the electric locomotives hauling standard coaches. Their principal advantage lies in their ability to perform the work of a steam locomotive in every respect, and this is frequently a strong point in their favor with the railway managers. They are thus able to accommodate themselves to congested traffic which usually occurs on holidays and possibly at certain times every day, by simply increasing the number of coaches hauled as is the practice with steam locomotives. Such locomotives should weigh from 100,000 to 150,000 pounds, should have eight wheels and four motors, so that the total weight is available for traction. They must be provided with sufficient power to haul at least double the average train without over-heating. They must not only be able to perform the work of a steam locomotive in the same service, but should do it at a faster schedule speed. The rapid acceleration of a train hauled by such a locomotive enables it to perform the above duty without any increase in the maximum speed. In switching cars, the ease and rapidity with which the electric motor can be handled is a great advantage.

It is necessary to equip these electric locomotives with the best automatic air brake system that can be obtained, for several reasons. They must operate the existing brake system on the coaches as well as the steam locomotive does. The law requires automatic brakes and a whistle. An independent motor compressor with a large main reservoir is therefore almost imperative.

The cost of repairs on an electric locomotive should be exceedingly low, possibly 10% of that required by a steam locomotive on account of the fewer moving parts and the entire absence of the boiler and its necessary equipment.

The fact that an electric locomotive requires but one set of controlling and air braking apparatus is a distinct advantage over other methods of employing electric motive power. This is evident, not only in the first cost but in the fewer parts to be cared for.

The second method of applying electric motive power to an existing steam railway; the equipment of standard coaches as motor cars, will appeal to all steam railway managers as the cheapest and most convenient way to make the change. This method has strong arguments in its favor.

The motor car carries its own paying load and during the hours of light travel can be run light, without hauling other coaches. A standard coach equipped with two motor trucks and four motors will haul nearly as many coaches as the electric locomotive above mentioned and weighs 100,000 lbs. It will easily handle five coaches making a six car train weighing loaded 450,000 lbs. I believe that the power consumed per passenger carried in a train hauled by an electric locomotive will be less than if all the cars were motor cars, whether run singly or in one train.

Let us see exactly what must be done to a standard coach to equip it as a motor.

In most cases the conditions will be found to be such that three or four car trains with a proper schedule will be sufficient to take care of the maximum traffic. This necessitates only two motors for the coach. These should both be mounted on one truck, and this truck complete with motors will have to be purchased and used to replace one of the standard trucks. The motor truck should be built especially for the purpose, a heavy steel truck, 36 to 40-inch, steel tired wheels, brakes of the type that do not require brake-beams, springs both elliptic, and equalizer of sufficient strength to support the weight of half the car body with maximum load, and this means all standing room occupied. The size and general design of the axle in the motor truck must be carefully considered. The author does not believe that steel axles 5″ minimum diameter between wheels, are safe. It may be that in calculating their strength and considering the enormous strains which they must withstand, the result appears satisfactory, but experience shows that the excessive vibration at high speeds will cause crystallization of the steel and a high factor of safety must be employed.

The wheel journals should be at least $5\frac{1}{2}''$ x $9''$, and the diameter of axle between wheels $6\frac{1}{2}''$, with a larger diameter through the axle gear.

The wheel base cannot well be more than seven feet, on account of the curves, but it is nearly all needed in order to obtain room for motors of sufficient size. The motor should not be supported by the truck frame in any way.

Steel bars should be placed at each side of the motors extending from one axle to the other, and beneath them, just inside the wheels. These should be suspended from lugs on the motor frame by suitable links as near the center line of each axle as possible. The backs of the motors can then be carried on these bars by means of other lugs on the motor frame and springs above and below the lugs. This method of motor suspension is rapidly coming into general use and it has many advantages. If motors should be damaged it is simply necessary to place another pair of wheels and axles with other motors in the same truck frame. The motor cars ride much easier, or practically the same as before they were equipped with motors, due to the fact that the jarring of the motors is not transmitted to the car body.

The motor car must be wired for, and furnished with a suitable number of electric lights and heaters, which is a simple matter. The same thing must be done for the coaches it is proposed to haul. The latter should also be equipped with collecting shoes connected by a wire which terminates at each end in an electric coupler of sufficient capacity to supply the motors on the motor car if necessary. The motor car is supplied with the regular air brake apparatus used by the road and piped as a steam locomotive, except that the car is double ended and requires an engineer's valve, gauge and other necessary parts at each end.

The independent motor air compressor, main and auxiliary reservoirs, car wiring cables, main wires for collecting shoes, rheostats and electric couplers, all go under the car in addition to the standard equipment of a passenger coach.

A small cab should be provided at each end for the motorman preferably inside the car, fitted with a front and side window which can beopened to their full extent. Here are located the air brake valves, the automatic governor and switch for the compressor, the motor controller, main switch, circuit breaker, electric light and heater switches. The bells or gongs, pilotsand whistles at each end complete the list.

A few words about car wiring may be of interest here. The most careful work in wiring cars is very essential. The author believes that the causes of nearly all the fires occurring in motor cars can be traced to defective wiring. There is no reason why such wiring can not be made safe. Even if the insulation of wires and cables is of the best, they should be treated as bare wires, as the insurance underwriters say, and unskilled labor does not pay in this part of the work. The maze of iron pipes, rods and braces, under such cars, render it necessary to protect the wires from rubbing or chafing with the utmost care. It must not be taken for granted that the pipes, etc. remain in one position when the car is under headway. The working and straining of the car body, the swing of the trucks and brake rods and compression of springs must be carefully considered, and no care in protecting the wires however great can make them too safe. In trolley cars the removal of the pole from the wire will put out, or render a fire easy to control, but in such cars as are under discussion, I have not yet seen or heard of a method of cutting off the current at or near the contact shoes, though there may be such. It is evident therefore how helpless a train crew is when called upon to put out a fire caused by a terrific arc under the car. It has been proved in practice that good car wiring practically prevents such accidents. Before leaving the equipment question, I will give some opinions on the performance of the motors.

For such short distances, and the intermittent work required, the modern railway motor seems well adapted. It can be overloaded, 100% frequently, without injury, for a short time. Most types of these motors have but one or two serious faults. One is lack of sufficient ventilation. During hot weather this becomes a serious matter, and one that should be corrected by the manufacturers. The design of the axle bearing, is another. In street car work, the plan of using a gun metal lining in halves, lubricated by grease or oil is fairly satisfactory, but where these bearings each become 15″ long and 6½″ diameter; at speeds of 40 to 60 miles per hour, the conditions are different, and while giving little trouble, the cost of repairs seems unnecessarily high. Most of the motors are similar in design to the ordinary street-railway motor, entirely enclosed by the frame, and intended to run in the mud and slush of a city street. On the other hand a steam roadbed is usually dry and clean, the motors are further above the ground, and water rarely flies above the axle. It would seem therefore that they could be more open on top. It has been found necessary to run through the hot summer months with the large covers over the commutators removed. The construction, and especially the insulation of armatures has reached such a degree of perfection, that a burn-out is seldom heard of in the larger motors.

I have had under my personal observation a considerable number of such motors, some of which have been in service over two years, making a daily mileage of over 300 miles, and have never had one armature burn out. In one case a pair of motors were in service eight months, including a winter. No repairs whatever were made during that time, beyond the ordinary daily inspection, cleaning, and renewal of carbon brushes.

In another case a pair of motors made upward of 100,000 miles after being put into service, the only repairs being renewal of armature and axle brasses, gears and pinions. As is well-known a frequent cause of burn-out in the past has been due to the wear of the armature brasses allowing the armature to strike the lower pole-pieces. This cause has been eliminated by making the clearance between the pole-faces and the armature slightly greater, possibly at the expense of an increase in weight of copper on the field magnets, and with no apparent loss in efficiency.

The total weight of a 60-foot standard coach equipped as a motor car with two motors will be about 80,000 pounds, without passengers, of which 55,000 pounds is on the drivers or motor truck. The speed of such a motor car running light, if geared sufficiently high, is probably only limited by its weight and the quality of its track and road bed. With a stone ballasted track, 100-pound steel rails, few curves, and those of long radius, a heavy car with the best steel tired wheels should run 100 miles per hour at full speed without difficulty.

I have mentioned a four-motor car consisting of a 60-foot car body weighing 100,000 pounds complete. This represents about 800 H. P. nominal rating of the motors at 650 volts direct current, and this is the maximum H. P. that can be placed under a standard coach, on trucks and wheels which do not necessitate any other changes in the existing standards of steam practice. The motors are capable of exerting double that power for a short time. The total cost of converting a standard coach into a motor car with two motors is about $3,800.

The third method of using electric traction in steam service, that of the use of light motor cars and trailers, built for the purpose, has some advantages. The former coaches can be used elsewhere on the system as are the locomotives. The smaller, lighter cars are cheaper to construct, the wear on the track is less, and there is considerable economy in power. It has been proposed, and no doubt will come, that such cars will run through the principal street of a city, on the existing street car track, before starting on their trip over the steam track. This would necessitate either a trolley wire over the steam track, instead of a power rail, or both collecting shoes and trolley pole on the car. There is no question but that this may prove a great advantage in time. On the other hand, the cars must be used exclusively on the line equipped with electric power. At speeds of 50 to 60 miles per hour which *must* be made in order to compete successfully with the existing parallel trolley lines, the cost of maintenance and repairs due to the excessive vibration will undoubtedly be greater than that with standard coaches.

The economy in power due to the reduction in dead weight hauled is of considerable importance, not only on account of the smaller amount used, but the line conductors can be lighter, greatly reducing their cost, or the system can be extended to longer distances at no more expense for transmitting the power.

In the future there may be a decided tendency to reduce the weight of electric trains. In other words, it will be an attempt to handle a constantly increasing traffic with a lighter equipment in order to haul less dead weight per passenger. The engineer who proposes to introduce such changes must move with the greatest care in order not to save the weight at the expense of strength. It should never be forgotten that the maximum load is "no standing room," that the strains on a car and its trucks running at 60 miles per hour over a steam track which may be made of 70-pound rails with joints none too good, are not to be compared with such as are met with in a city street at low speed. An interesting problem in connection with a similar equipment has arisen within the last few years, and the time is rapidly approaching when it must be solved. It relates to the difference between the wheels of street cars and the steam railroad coaches. Though both use the standard gauge of 4′–8½″ the average street car wheel has a tread 2½″ wide and a flange ¾″ deep, while the Master Car Builders standard requires a tread 4″ wide and a flange 1⅛″ deep. The problem is a serious one, for it intimately concerns the safety of the train. The steam railroad people after 50 years experience have settled upon the above standard, and the electrical engineer who chooses to ignore their experience in this, and in many other cases, runs a risk. There should be no doubt that it is unsafe to run the small street car wheels at high speeds over steam railroad tracks, with their present form of frogs and switches; and it is, in fact, impossible to run them on steel rails weighing 90 to 100 pounds per yard on account of the wide spaces in the frogs. The question may be asked: "Is it not safe to run such narrow wheels on the steam track if the latter be kept carefully to gauge, and proper frogs for these wheels are substituted for the existing ones?" If this is done steam trains can no longer run on the road, and, as it is necessary in order to round a curve at high speed with safety, to spread the gauge from ¼″ to ½″, the danger is greatly increased. On the other hand, the Master Car Builders' wheels cannot run on the existing street car tracks in our cities. The flange is too deep for the frogs, the size of the groove on the inside of the straight rail is larger than the city authorities would sanction, and the outside portion of the tread would in many cases run on the pavement and crush it down to a level with the top of the rail. The only solution of the problem seems to be a compromise wheel with about 3″ tread and 1″ flange. Whether or not this is safe, only time can tell.

The fourth question, that of hauling freight by electric power, should, of course, be decided upon at the time of installation, as it may cause considerable difference in the plans for power stations and line transmission. As the question can only refer to local freight along the line electrically equipped, it is of doubtful importance as applied to the conditions under discussion. If the freight traffic on such lines be sufficiently heavy to necessitate the use of a locomotive for several hours daily during the hours between midnight and morning when there are few if any electric passenger trains in service, it is economy to use an electric locomotive, for it costs but little more to run the power station, if it has been shut down, and the total expense would be somewhat less than that of a steam locomotive. The whole question of transportation of freight by electric power is one which concerns the future more than the present.

When the time arrives that long distances are electrically equipped on our steam railways, then it becomes far more important.

Power Transmission.

Feeders:—The transmission of electric power forms the most important part of the problem of the electrical equipment of a steam road. At the present day our railway motors all require the direct current, and we are therefore limited to its employment in the working conductor. By increasing its voltage from that usually employed to 700 volts, a considerable advantage is at once gained, and without additional expense in motors or generators. Experience has shown that the economical radius of operation of a power station generating such a current and delivered to the line without feeders is from 10 to 12 miles. This refers to a heavy train service with a fairly frequent schedule, and an average load of 500 amperes on each radial line of single track.

By the line or working positive conductor is here meant a steel rail of 90 to 100 pounds per yard, well bonded, and equal in conductivity to about 1,200,000 cm. of copper. The statement, "without feeders," may be wondered at, and a few words of explanation will be necessary.

It should be remembered that the conditions are very different from a street or elevated road. There may be only two, or at most three trains running. The greatest fall in potential occurs when a train is leaving the further end of the line, and this may be somewhat less than $\frac{3}{4}$ of a volt per ampere at that point, while the average efficiency of the line is over 75%. Again even if the loss in the line becomes greater through an attempt to increase the number of trains, or to extend the line, the question of feeders depends almost wholly on the cost of fuel. If the interest on the cost of feeders is greater than the saving in fuel consumption effected by their use, and a satisfactory train schedule can be maintained without them, it cannot be in the interest of economical operation to provide them. It has been said that such feeders in connection with a so-called booster used to overcome the drop in the feeders, and a consequent decrease in their weight, are the most economical. Such an arrangement is undoubtedly cheaper as regards first cost, but I have seen no data showing the cost of maintenance and depreciation of these additional machines, as compared with the cost of a feeder of sufficient weight to perform the work without the booster, and on which there is practically no depreciation. Whichever method is followed, the cost of feeders for such a road will reach many thousands of dollars, and railway managers will make the most rigid investigation of traffic conditions, present and prospective, before deciding upon such an outlay.

The above statement should make intelligible the reason why 10 or 12 miles is considered the maximum radius of operation of a station delivering 700 volts direct current. It is hardly necessary to add that a larger system extending over greater distances should be supplied by multiphase generators, and a high tension transmission line combined with the usual rotary converters, located at suitable points on the system. In the absence of a practicable alternating current railway motor, the above system is the only one—there is no choice.

In regard to the most economical material to use as feeders, the extremely variable prices of both copper and steel, renders it difficult at present to come to a satisfactory decision, but with both metals at what we may call their normal values, steel is cheaper and more satisfactory. The author believes a proper feeder for 700 volts direct current should be made of flat steel bars about 1″ x 5″ section, two of which are placed side by side, bolted together with alternated joints and supported on edge in the slotted tops of small posts set in the ground at the side of the road bed, not over two feet high and boxed in. At grade crossings the break in these feeders must be bridged by either an underground or overhead connection. In yards and stations where there is a multiplicity of tracks it will be frequently necessary to carry them overhead for considerable distances. Copper is of course used in such cases.

The Working Conductor—In considering a train service consisting of heavy trains running at the speeds mentioned, the trolley wire as a working conductor will probably not come into general use, although it is used for such a service to-day. The cost of construction, maintenance and depreciation is greater than that of a third rail. It has few advantages, and many disadvantages for such a service. It is now generally conceded that an insulated rail placed close to the track answers all requirements, and the author's experience shows that it is satisfactory. It is difficult to understand, however, why the common form of T-rail is so generally used for this purpose unless it is due to a desire to save money by using up old rails. A more inconvenient cross-section for thorough and efficient bonding could hardly be selected. It will be admitted by all that this conductor should be so bonded that when worked at its full capacity there should be no greater loss at the joints than elsewhere. There are a number of standard commercial forms of rolled steel which are no more expensive than T-rails that are well suited for this purpose. A form that will permit the use of one or more thin copper plates of ample area of contact held at the joints between a steel splice plate and the conductor by heavy pressure obtained by the use of a sufficient number of bolts, is an inexpensive and satisfactory bond. The rule that the bond shall be equal in carrying capacity to the conductor, and the area of contact equal to or greater than the cross-section of the conductor is a safe one to follow.

One question which has been studied with care is of great importance in this latitude, and that is the effect of ice on the contact surface, and how to get rid of it. Many experiments have been tried, and few can be said to have been successful. A further possible advantage of the use of some other form of rolled steel might result in the complete elimination of this trouble. I refer to the collecting shoes having a side or under-running contact. This would allow the partial roofing over the conductor by wood, which would thoroughly protect it from the weather.

Ordinary snow-storms and even blizzards do not interrupt the service. I have seen a storm which tied up nearly every wheel in a nearby State, but the electric service was the last to succumb, and even then it was not on account of the conductor rail, or too much snow on the roadbed, but from a train running off an ice choked frog. It has been demonstrated that motor coaches equipped with proper steel brushes for the third rail and snow plows, can go through as much snow as an ordinary passenger locomotive. Their great advantage lies in the fact that they can run through deep snow slowly, due to the enormous torque of the series motors and the absence of reciprocating parts. But when the temperature of the conductor rail is below freezing point, and it begins to rain, as is not infrequently the case, a coating of ice forms on the contact surface which closely resembles enamel. No mechanical method has been found to completely remove this.

As to chemical methods, certain roads can and do use salt or brine. It is not considered advisable to salt the road bed of such a road as is under discussion owing to the danger of leakage should the track become flooded with water. When applied at the right time, an oil which does not solidify at a low temperature is sometimes successful, but the difficulty of applying it to the whole road at the proper time can be appreciated.

Insulation :—The question of insulating the positive rail of a 700-volt grounded circuit has in actual practice been developed to such an extent that the results obtained are remarkable, to say the least. If such methods as are now in use had been proposed ten years ago, they would have been regarded as impracticable.

For years it was the custom to consider the ground a conductor of electricity. It was of course realized that the service rails must be bonded in some way, but the ground was considered to be a great aid to the rails in returning the current. I do not propose to deny that this is true in a crowded city where there are thousands of tons of iron pipes buried but a short distance beneath the rails, but can we call this a ground return? My experience shows that the road bed of a steam road consisting of sand, gravel or rock ballast, when dry, is a good insulator, and when wet there is but little difference. A rock-ballasted track in particular needs no insulation whatever except the wooden ties.

I am aware that such a statement may be regarded with doubt, but perhaps it can be made clearer if we take all things into consideration. The road runs through an open country, the soil is of the average composition, some of it wet, but most of it dry. If we stand on a wet spot and place our body in circuit from positive to ground we receive a shock, perhaps of maximum voltage. This would apparently show the ground to be a conductor, but a little thought will prove that it conducted a few milli-amperes only. If we stand in dry earth or on a tie, we feel no shock. But the one test that proves the insulation of such a line is the leakage test. From tests made every night, for over a year, the leakage averages $\frac{1}{2}$ ampere per mile in dry weather to $1\frac{1}{4}$ amperes in wet weather, and I am convinced that nearly all of this is in the underground work necessary at grade crossings and switch points. The above refers to a rail insulated upon creosoted wood blocks attached to the ties. A complete covering of snow, has little or no effect on the leakage. The form of the positive rail may influence the leakage somewhat. For example, the inverted V form acts as a roof to shed water and keeps the contact surface between the block and rail dry. But there is in use several miles of ordinary T-rail as a positive conductor, laid on blocks of wood $1\frac{1}{2}''$ thick attached to the ties, not creosoted, but dipped in an insulating compound. No leakage is noticable here. We can easily understand that if any appreciable amount of the current in amperes should leak through these blocks whether prepared or not, they would burn up. The writer, therefore, believes that such insulation of the positive rail for the current and voltage under discussion is ample, and much expense can be saved by steam roads by its use.

Track Bonding.—One of the most necessary and at the same time expensive parts of the work in changing existing steam roads into an electric line, is the bonding of the service rails. The author believes he has done some of the heaviest bonding in the country, and is of the opinion that there is no satisfactory method of bonding a T-rail at present. When such bonding costs two dollars per joint, it becomes a very serious matter. Bonding around the angle plate with the bonds about two feet long, is out of the question, for the cost of copper would be too great, and it would be exposed. Riveting the lugs on the bonds through the web of the rail, is not good practice, because to secure sufficient area of contact four holes would have to be drilled in the ends of each rail, which so weakens it as to render it unsafe. The shortest possible bonds should be used under the base of the rail. It requires four one-inch holes in the base of each rail, and we can easily see how unsatisfactory and expensive this is, with four bonds of 300,000 cm. area for each joint of 100 pound steel. In nearly all rail bonds the principal resistance is in the contacts. It is a simple matter to use sufficient copper, but to secure a proper contact is a difficult problem. The bonds must have the utmost flexibility to withstand the vertical motion of the rail ends, and even then many of them will gradually break off strand by strand. What is urgently needed at the present day is a cheap and efficient bond for a T-rail. Such a bond, to be satisfactory, must show no greater fall in potential than an equal length of the rail itself, when the maximum current is flowing through the joint. On account of the fact that the ground is practically of no value in augmenting the conductivity of the return circuit, the entire circuit must be regarded as metallic, and the ground should not enter into any calculations.

Power Stations.—The writer does not propose to enter into the subject of the design and arrangement of machinery in a power station for a steam road, as there are no engineering features which differ from those encountered in such a station intended for a large street railway. An abundance of water and cheap fuel are of course important points. Such power stations can be built for from $80 to $90 per kilowatt, exclusive of the land.

A few words about the amount of power required may be of interest. An important figure is the amount of power delivered at the switchboard per train mile. It eliminates all losses due to resistance of circuit, and current used for air compressors, electric lights and heaters. This figure will vary from four to six kilowatt hours per train mile, reaching its maximum in December and January, due to the longer hours of lighting the cars, the constant use of electric heaters, and the frequent running through snow.

The question of heating a standard coach by electricity is one that should be thoroughly understood. Street car heating is totally different. The public demands the same temperature as is furnished by steam, which is 68° or 70° F. It makes but little difference what heater is used, provided there are enough of them. One may radiate its heat faster than another, and so raise the temperature of the car more rapidly, but it will require, in any case, from 12 to 15 kilowatts of energy for each coach. An ordinary train consisting of a motor car and two coaches weighing 200,000 pounds, will require, at a speed of 35 to 40 miles per hour on a level track, about 125 kilowatts, or about 166 H. P., of which the motor car alone would consume 75 K. W., if running light. The motor will consume an average energy of four to five kilowatt-hours per train mile, or 40 to 50 watt hours per ton mile. Power can be produced with condensing engines and fuel at about $2.30 per ton, for about .008 ($\frac{8}{10}$ of a cent) per K. W. hour.

Cost of Operation:—It is most desirable in operating a heavy electric service over a railway on which steam trains are also operated, to arrive at a satisfactory conclusion as to the comparative cost of operating each type of train per mile. If an electric service is entirely substituted for one which has been operated by steam, the railroad company is in a position to know accurately the difference in cost of the two systems. But when both are operated over the same tracks the problem becomes very complex. For example, even if we omit the maintenance of the road way, which may be a little higher in an electric service, there are many other items such as salaries of agents, ticket sellers, gatemen, etc., all of which properly belong to the operating department, which must be proportioned between the two services. It may be said that the cost of operating a steam passenger train has been estimated all the way from 30 cents to $1.00 per mile depending upon the length of the train and other conditions which are seldom alike in the different localities. The author cannot go into this subject in detail, but will give a few points of difference between the two services upon which an approximate estimate can be based. A fair average cost of running a steam locomotive, including fuel, when coal is about $2.30 per ton; water, wages, repairs etc. is 22 cents per mile. The average cost of repairs to coaches may be taken at one cent per mile each. The wages of train crew, consisting of a conductor, baggage master and one brakeman will average .05 per mile making a total of 30 cents. This figure is intended to represent the lowest possible cost of operating a train of only three cars by steam with the understanding that it is kept almost constantly moving for about 9 hours, and covering from 150 to 200 miles. It is well known that a train making but a few miles per day cannot be run at a profit, either by steam or electricity, due to the fact that cost of wages per mile increases rapidly, as the crew has to be paid the same in either case. A great advantage of the electric service may be mentioned here. The above service is all that can be required of one crew and one locomotive, but the motor car can easily make 300 to 400 miles in 18 hours, and as the daily service is in operation at least that long, one motor car does the work of two locomotives. In the operation of a similar three-car train in which one car is a motor car, we will assume the same crew with the addition of a motorman and omit the locomotive. The cost per mile in wages will then become 6½ cents, that of repairs to cars the same as before, 1 cent, maintenance of motors, ½ cent and cost of power delivered to train, 6 cents, making the total cost per train mile, 14 cents for the electric service.

Electric Lighting.

All steam roads, which have introduced electric motive power, will consider the question of lighting their passenger stations and freight houses along the line. It will be found that lighting in this way is very satisfactory and far cheaper than the purchase of gas or electricity from others. For lighting freight sheds, platforms and other outside lights, the simple wiring of the lights in groups of five or six in series, and connected directly between the feeder or working conductor and the service rails, has been found satisfactory. The occasional interruption of the current due to the opening of a circuit breaker will shut off these lights for a few seconds, which makes them inconvenient for in-door lighting. For stations requiring not over 60, 16 c.p. lights, a small storage battery of 58 cells, together with a rheostat and switchboard with the necessary switches and instruments can be installed for about $900.00. By making the rheostat of about 55 ohms resistance and 35 amperes capacity and connecting it in series with the railway current, it can be used to charge the battery.

The battery and rheostat are connected in parallel with the lighting load, and the resistance so regulated that the railway current does the lighting, the battery merely acting as a regulator, charging slightly when the voltage rises and discharging into the lighting circuit when the pressure falls, due to the movement of the trains. This maintains a practically constant voltage of about 120 on the lighting circuit, and the battery does little or no work except when the power station is shut down. The principal advantage of this arrangement is that it is practically automatic in its action, and requires no regular attendant. The station employes can handle the switches when necessary to turn on or off the lights. An occasional inspection of the battery is all that is necessary. The cost of such lighting is much less than it can be purchased from lighting companies. In larger stations requiring several hundred lights, a motor generator can be used instead of the rheostat and connected to the battery and the load in exactly the same way. Such a plant should have an attendant.

Discussion at New York, Feb. 28, 1900.

Mr. Frank J. Sprague:—Mr. President and gentlemen, I have been asked to open this discussion, and I have been spending a part of the afternoon looking at a time-table. I have listened with interest to Mr. Boynton's paper, giving the principal results of his experience on the New York and New Haven road. If I have any criticisms to make of it as a paper, it is that it does not treat of the subject on quite as broad lines as I would liked to have seen. It is more a record of what has been creditably done, with interesting results, in connection with work of the New York and New Haven Railroad, inaugurated at a time when there was a good deal of cynicism expressed. I will take the liberty, if I may, of going back to a review of this subject, and reading from lines written some five years ago, and then make reference to some projects which are now in hand. I think, possibly, I might suggest a title for Mr. Boynton's paper, something like this: "Shall electricity be used on steam railways, and, if so, how far and under what conditions?"

In the paper referred to I stated: "Electrical development will go on until the trolley system is almost as common as the turnpike. It will establish lines of communication which have not hitherto existed; it will build up new territory; it will act as a feeder to great trunk-line systems, both for passenger and certain classes of freight work; and it will largely encroach upon special fields now occupied by the trunk lines.

"But, when we depart from this class of service and take up what is essentially a trunk-line system, there are many questions to be considered, and not alone those of the local and express service, but also a most important one, which is rarely considered when electric railways are talked of. I refer to the trunk-line freight service—that is, the transportation of goods in great bulk over long distances. One must remember that trunk lines, as they now exist, have been built up by a slow process, and that no very serious change from their existing conditions can be made, considered from the commercial standpoint, except after grave deliberation and at very great expense. Unless passengers and goods can be moved over a system with increased benefit to a community, or at a reduced cost, or with a commensurate return on capital invested, an electric will not replace a steam system. Of course, in these remarks I ignore specific problems, such as the utilization of a storage battery and motor in place of a locomotive, or of a moving central station, as is being tried on one of the French lines, or those special problems like the Baltimore tunnel, in which an electric locomotive will be utilized for a short distance in place of the steam locomotive; I am considering the possibilities of what is generally considered an electric system—that is, the operation of a number of train units from a central station.

"If we were to refer a moment to any other system of transmission of power—for example, by water or air—no one for a moment would question its limitations. We all know that any amount of power can be so transmitted, but only with definite losses which depend upon the pressures used, the sizes of pipes, and the distances and amount of energy transmitted. So it is in the transmission of electricity, which is nothing more or less than an agent whose exact character we do not know, but whose obedience to certain empirical laws is absolute.

"It is unnecessary here to repeat the specific laws covering such transmission; they are perfectly well known, and there is no practical hope of their being changed, any more than the laws of gravity. Recognizing these laws, there is a distinct limitation to the distance and amount of power which can be economically and conveniently transmitted and distributed, no matter how perfect the generating or receiving machinery may be; and these two particular elements have been brought very nearly to their maximum possible efficiency.

"It may be said—which is perfectly true—that, if from a central station one can conveniently operate a number of distributed units over a 20-mile road, why cannot two or, for that matter, a dozen such systems be connected together? So they can, but this does not form a trunk-line system. Of course, if we consider the steam trunk-line from a passenger standpoint, the present system has defects, and the principal one is the inconvenience of service when considering short distances. If one is going a long distance then it matters not so much whether the trains are two or three hours apart in leaving; but long-distance travel and short-distance travel have not the same requirements so far as the passengers are concerned.

"If nothing is sacrificed, it would be preferable, of course, to have smaller units despatched at more frequent intervals, no matter what the distance of travel, but, as I say, this is less important when dealing with long distances than when dealing with short ones. When trains are operated in large units, with comparatively few units between terminal points, and these at considerable intervals, the steam locomotive will absolutely hold its own. When, however, these larger units are broken up, the intervals of train-despatching can be shortened as much as is consistent with satisfactory operation and the number of units distributed over a line made correspondingly large; then, and then only, will electricity be used on suburban lines and lines connecting important cities.

"I have again and again advanced the substance of this statement, and I must here repeat and emphasize this fact—that, so far as passenger service is concerned, considering for the moment only economy of operation, the problem narrows itself down to the number of train units operated between terminal points. Make that number sufficiently large, and the electric motor is the best means of propulsion, whether for high or low speed. Decrease this number, and you must rely upon steam.

"Or, putting it another way, the answer to the query, will electricity take the place of steam locomotives for railway service, is: only in part, and then only when the number of units operated between terminal points is so large that the resulting economy will pay a reasonable interest on the combined cost of a central-station system of conductors and the motor equipment, and the traffic existing is commensurate with the needs of such a system.

"It is perfectly true that looking only at the time standpoint of passenger traffic it is entirely possible and feasible even, not only to operate any existing street or elevated system, and many of the suburban systems, but also the traffic between such points as New York and Philadelphia on a subdivided electric service; but this is not all that is required. The more frequent the units despatched over the track, the more exclusive must be that particular track for that particular service, and the larger must be the number of tracks to take care of all the varied service of a great system.

"Briefly, the service may be characterized as the transmission of passengers from one local point to another and the transmission at high speed between principal points—that is, way and express service—and the handling of freight in great masses with all the attendant switching and distribution at way and terminal points. Considering only the transit needs of these various services, a six-track railroad might be considered desirable, and probably would be; but there are many problems connected with such a road, to say nothing of the fact that it would often be impossible to construct such a system on existing rights-of-way. Independent of the matter of investment, rights-of-way, or construction, the problems of switching, passenger landings, and freight acceptance and delivery, on a six-track railroad would be a grave one.

"Freight cannot be handled like live loads. A succession of cars, each with twenty or thirty passengers, might well take care of all the passenger traffic on a road, but freight cannot ordinarily be handled in any such way, except by an enormous increase of expenditure. The 30-, 40-, or 50-car train, pulled by a single locomotive, with a limited train crew, presents an economical transportation of freight which no system of units on long-distance transportation can hope to equal.

"It may be contended that there is a way to create a six-track service, and that it can be operated partly electrically and partly by steam, and that the small units for way service can be run on one set of tracks, the express units on another, both subdivided, and that larger freight units at long intervals can be operated on the third, but this proposition will not appeal with any practical force to the railroad man, or to the electrical engineer as such, because it is absolutely vital for successful electrical operation from a central station that the units shall be divided, and that there shall be a distributed service, and not a localization of large units at long intervals at any portion of the system.

"It seems hardly necessary to even refer to the question of signals, and all the difficulties which would exist if an attempt were made to operate a road simultaneously with electricity and steam. Human life and its absolute dependence on these signals, which neither natural laws, stress of accident, or conditions of weather should interfere with, make this of vital importance in considering any change.

"One of the great advantages of the electric system, as generally used, considered from a traction standpoint is the fact that the motors are carried under each individual car, or, with few exceptions, under one of two or three cars, thus giving the advantages of a higher proportion of weight for traction, with a consequent distribution instead of localization of weights. When motors reach their highest standard every car can be made an individual unit, which can be operated in any combination and from any point of a train; but this advantage instantly disappears when it is attempted to use an electric locomotive after the manner of a steam locomotive. That is, to put it ahead of a number of car units whose aggregate weight may be from five to twenty-five times its own. It must, then, in a large measure be limited by identically the same laws in the matter of weight and traction as the present steam system. Assuming units which are common on steam roads, such as 1000 or 1500 H. P., the enormous loss of energy and the variation of pressure on a line would make the cost, with any possible allowable loss, entirely impracticable.

I have seen little development in the last five years to alter those general conclusions, but I am no less a believer than ever in the gradual and certain encroachment of the electric upon steam railways. If I were asked, however, if electric traction will take place "under steam railway conditions" I would say no, except in special cases. What are steam railway conditions? A more or less perfect roadbed, which gradually becomes a more or less exclusive roadbed, and the more exclusive it becomes the better it is for electric railways; stations at predetermined positions and distances of signaling; operation on the same or on separate tracks of express and local service and freight service, which complicates the problem; operation under a fixed time-table, with varying lengths of trains, but always large units, with a tendency to larger ones. These are essentially steam railway conditions. Many of them are directly opposed to commercially successful electrical operation.

There are two things which have been brought forward and practically developed in the past three years which are not mentioned by Mr. Boynton as having a possible use in future electric railways. The first is the storage battery. Its use on the South Side elevated in Chicago, on which I have 180 cars in operation, the experience on the Metropolitan road in this city, and the general introduction on a large number of other roads and central stations, primarily for the purpose of equalization of load and for taking a small portion of the peak load at certain hours, warrant the statement that it is certain to be a feature in railway development. There is no doubt in my own mind concerning this. Another development is the method of controlling two or more units or cars equipped with motors from a common source, which I have called and it is now known as the "multiple unit" system, subject to more or less ridicule and criticism during past years, but now being generally accepted as necessary in modern transportation. I do not mean by the term "multiple unit system" the equipment necessarily of every car in a train, but the equipment of two or more cars of a train under a simultaneous control. Neither of these developments are mentioned or considered by Mr. Boynton. If there be a question about this latter proposition, let me recite what has been proposed with eight or ten roads representing modern work. The Illinois Central Railway, with its six or possibly eight-track service, stands as an example to-day of the most perfect steam suburban service. For two years and a half at least actively, and for four or five years before that tentatively, its management has considered the application of electricity to that suburban service. Bear in mind that before we undertake the larger problems we must take that which is at hand; that is, suburban service 20 or 30 miles out of the city. So we will consider this Illinois Central road. The conclusion arrived at some two and a half years ago was that from the standpoint of steam economy nothing whatever was to be gained by the adoption of electricity under the conditions which exist in Chicago on that road at the price they paid for coal and with the duty they are getting out of the engines; that in the matter of speed, that was already very satisfactory on the express service, but for the way or suburban service electricity offered an advantage, permitting an increase from 18 to 23 miles schedule speed. But all consideration of a locomotive or a locomotive-car pulling a number of cars has been put aside for a finality. The only thought, I think I may say fairly, which they have had in mind is one expressed by the then Chief Engineer and now Assistant First Vice-President Wallace, when he said in effect to me, some two years and a half ago, that he wished to see the abolition of the time-table on suburban service, and to be able to direct at frequent and regular intervals the going out of train units of one or two or ten cars, without unnecessary switching, without a locomotive at the head to pull them, motive power and capacity always holding like proportion to each other, with orders to leave the terminus and get back there as quickly as possible, without waiting at any station for the time-table. He said: "I hope to see cars operated by a push-button." It happened at that time that I was in Chicago, connected with the Chicago South Side elevated, and I told him that that was what I was there for. Shortly after that the equipment of the South Side road was taken up. If that road adopts electricity they will put on their cars not less than 300-horse power, and those cars will be operated in any combination from one to a dozen cars. Such radical operation requires, for the best duty, a storage battery to help equalize the load and to take perhaps a little of the peak. If alternating currents are used, with rotary transformers delivering constant potential on the line, it is out of the question to put upon the sub-stations the sharp, varying loads which would be required, without a storage battery.

The Liverpool Overhead Railway operates at present three-car trains, with motors on the front and the back car. The Waterloo and City Railway of London operates three and four-car trains, with motors on the front and back car. The Union Electric Company of Berlin has recently submitted a project to the Minister of Public Works proposing the change over from the present steam system to an electric system, working as many as 12 cars in a train, each car being equipped with two motors of 150 H. P. capacity each. The new Berlin Elevated Railway, of which Messrs. Siemens and Halske are the prime movers, are considering the operation of four and five and even up to ten-car trains, and they have had under consideration all sorts of methods—four-car trains, with three motors on the front and on the back car; four-car trains, with four motors on the front and back car; five-car trains, with two motors on the front and back car; ten-car trains, with two motors on the first and rear car and two motors on a middle car, and a full multiple unit system.

The new Boston Elevated road will have an equipment of two 150 H. P. motors per car and operate them in from two to five or six-car trains, all under a common control. The Manhattan—well, none of us can speak with any definiteness about that yet, and therefore I will not prophesy.

The Brooklyn elevated will operate from three to five-car trains, with two and three motor-cars in a train, and contemplate eventually equipping every car, all under a common control. So it would seem that in electric railways the idea of grouping together units and controlling them from a common point is the accepted engineering conclusion, no matter who does it or what the specific apparatus. If a railroad is operated either with one-car units or two-car units or six-car units all the while there would be a definite determination of the motor equipment for that unit. If instead of being constantly operated with one size train units, it is operated with trains which are made up of a varying number of units, then it seems reasonable to suppose that each of those units should be equipped with the power and only with the power that is necessary to drive them.

Some of you are suburbanites. I am not, except as to my shops. The advantages (or disadvantages) of New York are such that to get out we have either to burrow or float, go through a tunnel or go over the water, and I have often to take the Delaware, Lackawanna and Western Railway. I picked up a time-table this afternoon, and I was a little surprised at some of the conclusions which a graphic setting out of that time-table showed. You know that from Hoboken there is a two-track stem with some freight sidings that runs to Newark and up to the Roseville Avenue Junction. Thence a branch goes to Montclair. From Roseville avenue the main stem of the road runs out to Summit, Morristown, Dover and on. Taking the latest time-table, I have laid out the trains on a graphic method, based on number of trains and times of transit. The distance from Hoboken to Roseville Avenue is about nine miles, thence to Montclair four miles, and from Roseville avenue to Morristown 21 miles. This road may be taken as typically representative of a suburban service, and is right at hand. At present one crosses the ferry every 10 or 15 minutes and finds a train every 40 minutes or every hour and 10 minutes, just as one goes on the Manhattan elevated to 155th street and then finds trains to Yonkers anywhere from 10 minutes, to an hour and 10 minutes apart. The aggregate roadway here considered, is roughly 34 miles, and the actual single trackage about 66 miles. Between about five o'clock in the morning and one o'clock at night there are 144 trains in operation on either a part or the whole of the distance over those lines from Hoboken to Montclair, or to Morristown, 31 miles away, leaving out those trains which go beyond Morristown. I have considered their limit of service because it is within the reasonable limits of transmission of an alternating current from a reasonable center. Perhaps it would surprise you to know that despite that number of trains there are times—considering no stoppages whatever at a station, but only the time from departure to arriving—between five o'clock in the morning and one o'clock at night when there is only one train on this 66 miles of track. That is a steam railway condition, but not one which will ever be adhered to if the road adopts electricity. Considering the stoppages of trains at the different stations, there are probably not less than 20 times during these hours in which there is not a car moving in all those 144 trains that operate within the 30-mile radius of Hoboken—not less than 20 times within the day when there is not a wheel turning on 66 miles of track, despite the fact that this road is supplying 20 or 25 populous suburban towns. It has been said that that road is considering the adoption of electricity. It is a perfectly practicable engineering problem and entirely feasible commercially. As at present run there are but from 1 to 13 trains in service, and from about 3 to 65 cars maximum. The equipment to get the best service should be with not less than one-half of its cars equipped with motors, and I question

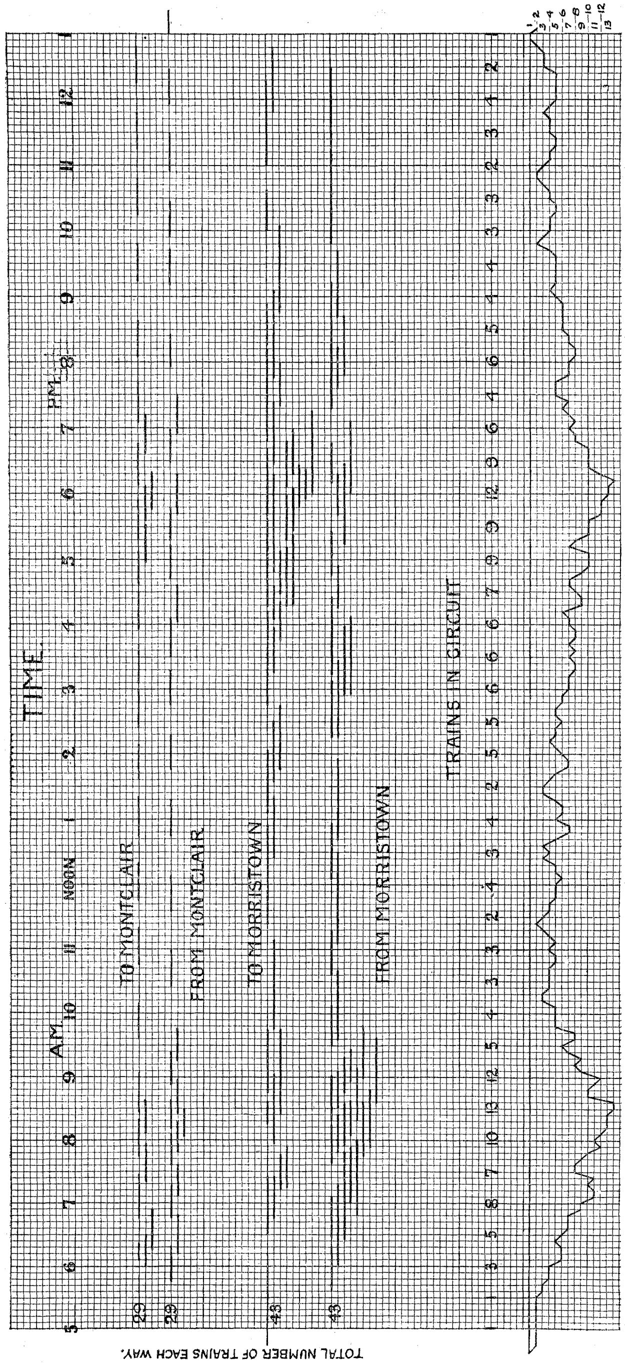

FIG. 1.—Train Time Diagram, D. L. & W. R. R. Suburban Trains to Montclair and Morristown, and Between.

if it would not be better if every one of its passenger cars were, but certainly not less than one-half.

There are two things you have got to consider in traffic. One is to meet the wants of the individual man. He cares little what anybody else wants. He goes to a station and wants to go home or to business. The other is to meet the collective wants of these several men. Scattered throughout the day there is a fair average of people who wish to travel, and at certain hours of the day there are large numbers of people who have a similar desire. So we have to consider not only the frequent dispatching of trains, but the variation in size of those trains. If one-half of the standard coaches on a road were equipped with motors under conditions that would make it possible to operate two or a dozen cars under simultaneous control, the cost of the car equipments would probably not exceed one-quarter the cost of a single one of the generating units required for the Manhattan Railway, including its engine, steam piping, and proportion of building. The power required to operate this 34 miles of suburban road would be equal to about two of the Manhattan units, and but very little more than is being used on the South Side elevated in Chicago.

It seems to me that the broad question of using electricity on a road is one which is to be determined absolutely by the frequency of service which that road will stand, and the more the short-distance trains are operated electrically the fewer the steam trains going to long-distance points, which must operate over that road. I will content myself by simply prophesying two facts: one is that the storage battery is a necessity in any large development of the application of electricity to railroads, and the other, that the aggregation and control of two or more units in a train—that is, the multiple unit system will be the future method of operation.

Dr. Cary T. Hutchinson:—I think Mr. Sprague has entirely misunderstood the intent of this paper. I do not think it is intended to discuss broadly the most economical method of operating trains by electricity, but was intended as a resumé of the author's experience in handling suburban trains; and it tells what the author has learned. There is no intimation whatever in the paper that any consideration of the economics underlying electric railway service was intended; but there are many interesting results of his experience; among others, the very low cost of repair of electric locomotives, only ten per cent. of that for steam locomotives. I do not think this would hold as an average result or even an approximation. The figure of four to six kilowatt hours per train mile for train service without mentioning at all the weight of the train or the schedule is indefinite. It is generally understood that the energy consumption per ton-mile may vary in the ratio of 1 to 10 for different schedules.

There are a number of other facts of that kind that might be discussed, in particular, the performance of motors, etc., for above ratio. What is the ratio?

MR. GEORGE T. HANCHETT:—I note in the paper that Mr. Boynton mentions an 800-H. P. equipment of four motors. That means a 200-H. P. motor. I had the good fortune to observe the experience of a prominent company manufacturing railway motors of that capacity. They were used in elevated work. They were installed within a 6-foot wheel base with a 33-inch wheel. They filled the space. There was hardly room enough for the brake rods. The motors had to be mounted on an odd angle in order to allow the car axle to thread through the casing between the pole-pieces. It was found necessary to keep these motors open both above and below the bearing on both sides in order to safely rate them at 200 H. P. If I remember correctly, the temperature rise was something like 75 degrees centigrade above the atmosphere. If those are the facts it is necessary to keep the casings open if we are to use 200-H. P. motors in such work. Such ventilation was mentioned by Mr. Boynton as a luxury which might be enjoyed under certain circumstances, but I think it is a necessity if the experience of this company is to be believed.

MR. RICHARD LAMB:—Speaking of open motors in suburban service, I have recently been called upon to build a trolley line at Brigantine Beach, N. J. The ocean had cut away the beach, leaving the trestle out from the shore a distance of about 200 feet. One of their experiences was that when the tide was in and the waves were high they would have an armature short-circuited and burned by the salt spray entering the open motor. On one occasion they had one of their large generators in the power-house thrown off of its foundation, from the ocean spray short-circuiting an open motor on a car two miles from the station, the circuit-breaker having failed to work. They also had the experience of the sand blown into the open motor by the winds, cutting away their commutators and journals. They tried putting what they called a canvas petticoat around the opening of the motor. This raised the temperature excessively. These experiences prove the absolute necessity of using completely encased motors in any suburban service having seashore road-beds.

MR. ELIAS E. RIES:—Mr. Boynton, in his paper, although he mentions and describes the various methods he speaks of as relating to the operation of electric railways "under steam railway conditions," it seems has confined himself more or less to short lengths of lines of about 10 or 12 miles, such as are and have for some years been successfully operated by direct or continuous currents. The application of electricity to such short lines of steam railroads I should regard as operating steam roads "under electric railway conditions," rather than under steam railway conditions. I believe that the thing which electricians and engineers in general have chiefly in mind when it comes to the question of substituting electricity for steam on railroads is the electrical operation of long lines, or trunk lines. That, it seems to me, can only be successfully accomplished when we have arrived at the point when we can supply alternating currents of high tension for transmission purposes and convert these into currents of lower tension for the operation of the motors. This matter is incidentally touched upon in Mr. Boynton's paper, but very little has been said here to-night in regard to it. It is a subject, however, too lengthy to be discussed at this late hour and I will therefore pass it by, notwithstanding that I believe the solution of this problem necessarily rests upon the adoption of such a system.

There was one interesting point mentioned by Mr. Sprague in his discussion, stating his belief that in any rotary converter system operated by high potential currents for long distances, it would be necessary to combine with it a storage battery. It struck me that there was an interesting possibility in that application when you come to the question of the general problem of operating trunk lines or long-distance railway lines with infrequent long-train service by electricity, and that is this: The great difficulty in adapting electricity to steam railway operations is that the present steam locomotives are fairly economical because they carry along their own generating capacity, which is not only sufficient for, but is applied locally to, the work of hauling the train; they require a certain crew, limited in number, and their most economical condition of operation is to haul as heavy a load as the traction ability of the locomotive can sustain. The electric system, on the other hand, which requires fixed stations for generating current that must be transmitted over the line whether there be only one or a dozen trains on a section, demands that its generators be operated at the highest efficiency—that is to say, at practically full load at all times, preferably 24 hours out of the 24, and it would be a great waste if those generators, which must necessarily be given a power capacity greater than that required to move the heaviest single train at the required speed, had to remain idle for a period of anywhere from one to four or five hours at a time between trains.

Now, it strikes me that it is just possible that a system of generating stations could be combined with a storage-battery plant in which the battery would be used, not merely for compensating for the difference between the peak of the load and the level load; but it could be charged by generators of rather moderate power running all the time, the battery groups being so connected as to give forth their energy for comparatively brief periods in large amounts (to feed long, heavy traffic trains running approximately under steam-railway schedule conditions at more or less infrequent intervals), on the principle of the accumulator in a hydraulic system, or the flywheel in a punching press, etc. In that case the current might be generated and transmitted as a continuous current, feeding, at intervals along the line, storage batteries connected in series, and the latter might be arranged to automatically discharge into the service or working circuits in multiple, at ordinary working pressures, whenever a section is entered upon by a train, and so on. I merely mention this as a passing thought—that that seems to be one way in which the existing steam-railway conditions could be maintained under electrical operation *if* it were desirable to do so. I do not advance this, however, as a desirable solution by any means, as I believe it will be found better to modify steam-railway conditions so as to conform to what has been found best in electric practice. It simply occurred to me and I thought I might mention that as an interesting possibility. The general subject is one of considerable importance, and I am very glad, indeed, to have heard the INSTITUTE discuss the matter so fully this evening.

THE SECRETARY:—There have been some criticisms on the title of this paper, and whether they are just or not, I am not certain that it should be left for the author to defend, because whatever the title is, it was originally suggested to him, and then after he adopted it, it was changed; and, as a matter of fact, I do not think he is responsible for the title at all. What this is, and what it was attempted to get, is some notes or some information in regard to the operation of trains by electricity, over the same road and under the same conditions where they had previously been run by steam. Perhaps some of you may be able to fit a title to those conditions, for that was what the Committee on Papers was trying to get at, and it went to the only known place in this vicinity where electric trains were operating under those circumstances.

There are certain interesting questions involved in such a radical change of operating conditions as noted in this paper. I served on a railroad for two years before I went into telegraph work, and I have ridden on a steam railroad as a suburbanite for 33 years, and I can speak as a practitioner in early days, and an interested observer of modern methods. I have recently had an opportunity of comparing a steam express service with a fifteen minute interval and a trolley occasionally connecting with it on a twenty minutes headway. But the superintendent found that they could not quite make the schedule under all conditions. He said that if things were all right, that they could make the time under twenty minutes headway. But sometimes things happened —cattle or old women or wagons got on the track and delayed the cars, so they changed the schedule to 22 minutes, making it 66 minutes in the hour, as you might say. It has been a problem ever since that road changed its schedule about six weeks ago for the people on the side streets to find out when a car would be along.

It appears to me that people who undertake to manage a service of that kind should study the conditions of life and the conditions under which people travel on the cars, as well as taking up the technical questions, because in this particular case there is a great deal of traffic comes on the connecting steam railroad. It is not so much the question of the time-table as it is having the cars run at regular intervals in each hour. If they run every 30 minutes and start on the even hour, you know there is one every half hour; that is all right; all that is perfectly clear and easy, and so it is when they run every 20 minutes or every 15 minutes; but when they run every 22 minutes, making a variation of six minutes in every hour, it begins to be a brain-racking performance to keep track of it.

Getting down to some of the technical points that are brought up by Mr. Boynton, he mentioned this third rail, and the difficulties of bonding with that particular form of rail, and it occurred to me that it would be a very simple matter, if there was any amount of business in this, to make a form of rail for a conductor that would be satisfactory. Then there is a question as to the position of this third rail, whether it is to be outside of the two rails or between them, or near to one, or in the center. I do not see any information in the paper as to the best position.

In regard to ice on the track, while we have comparatively little of it, it does not appear to me that this is an argument against the use of electricity. Where it is an annoyance, and in certain climates it would probably be worse than it is around here, it appears to me that it could be gotten over very readily by an economical device. Even if this could not be done, we might as well say that the locomotive is a failure, because sometimes it gets snowed in, as it does, and becomes one of the most helpless pieces of machinery that you can imagine, when it is packed in the snow. Regarding speed possibilities, I would like to inquire as to the distance required for getting up the speed of these short trains, for this reason, that a few years ago, when what was then a record run of 72 miles an hour, was made on the Bound Brook route, that train ran 12 miles before attaining that speed. I believe there is only one place on that line where the track is in such condition that they can make such time, and of course when you consider that it takes 12 miles, as it did at that time, why of course frequent stops make it practically impossible, and it appears to me that before dismissing the subject, we ought to consider this question of speed a little more, because it is very important, as some of the predictions in regard to the speed of electric locomotives have not been verified in practice. The probabilities are that one of the reasons is that there are very few lines in the country that are well enough built and have a sufficiently long stretch of reasonably straight and level track so that they can attain the speed that we have had in contemplation.

Mr. Harrison Anderson:—I came here this evening as a stranger and guest, and one of my reasons for coming was that I am browsing around everywhere. I came in search of information and instruction, and I like my instruction very much as I like my whiskey—I like it straight; and I can illustrate what I mean by an experience that I had a couple of years ago in the west, when I was trying to sell a very fast steamboat to Mr. J. J. Hill, of the Great Northern. While we were out on this steamboat together, naturally, Mr. Hill instead of talking about my steamboat was talking about his own railroad. I was very willing to listen. He said: "You can write the whole secret of successful railroad operation on your thumb nail. I have men who have been in my service for twenty years and have not got down to the fundamental facts of successful steam-railroad operation. It is that expenses are by the train mile and receipts are by the ton mile. That is all there is to successful railroad operation." I came here this evening hoping that I would hear some formula of that kind that would give me an absolute grasp of the successful operation of electricity as replacing steam on the railroads.

Mr. Sprague:—Possibly I can give the gentleman some information on that point. The South Side road in Chicago, of which I have spoken, was a steam road operated by Baldwin 28-ton compound locomotives, hauling from two to five cars. The saving at the present time is about $500 a day for coal alone. They are also saving in transportation expenses. The actual cost of the operation of the road, exclusive of taxes and licenses, is seven and a half cents per car mile of 22 tons average weight, including passengers, and stopping at intervals of about 2,000 feet, on a schedule of 15 miles an hour.

No one here has spoken of the somewhat interesting experiment made in Germany on long-distance transmission. Mr. Reichel, the chief engineer of the Siemens and Halske Company, was here a short time ago and he told me of some experiments he had carried on in the transmission of an alternating current at 10,000 volts over a small line, from which the current was taken directly to the locomotive, on which was a transformer, connected with which was an alternating current motor. His object, of course, was the reduction of the cost of transmission for spasmodic service over long distances, and with a small arc of contact to get a large amount of energy from a small overhead wire. I do not know how successful the experiment was, but it at least was tried. But on the new Berlin elevated railroad they are going to use the continuous current at 700 volts.

I notice, speaking about the cost of some things, that $80 to $90 was given as the cost of the central station per kilowatt output. The cost in the stations laid out in this city at present is over $200 per kilowatt, including engines, dynamos, switchboards and such proportion of the building as is required to cover that particular unit. There has been some rise in prices in the matter of machinery recently.

On some elevated roads ice is kept from the third rail by running a fast car or train over the lines on seeing the approach of sleet. With the more or less reliable weather prognostications, it becomes possible generally for a good weather man to state whether he is going to have sleet on the track or not, and sometimes they run over the line and grease the third rail. That is done on the Brooklyn Bridge. It is sometimes done on the main section of the Fifth Avenue road. Where there are a number of cars in operation, and the main current is carried from car to car, then the shoes on the forward car are apt to break the sleet, and those on rear cars do their duty of supplying the main current. I have seen five cars coupled together in a train on a track very heavily coated with sleet, in which the forward cars broke the sleet coat completely, and there was scarcely an arc of any kind on the brushes which made the actual connection, because there were so many connected together.

Mr. George F. Atwood:—I would like to ask Mr. Sprague or Mr. Boynton if there has ever been any other form of collecting shoe tried than the ordinary type of shoe?

Mr. Sprague:—I do not know of any that has been tried in every day use. The Union Electric company of Berlin proposed the use of a side shoe. Sleet is not always formed on the top of the conductor alone. It is oftentimes formed on the side by the wind drift. In Boston proposals were originally made for covering the tracks with a sort of shed. I don't think that will be carried out. The project in Berlin calls for a covered track, but I doubt if that will be finally adopted. Where you have a number of trains in operation and can connect cars, you can almost always overcome any sleet storm which may occur.

Mr. Atwood:—You never use a rotary shoe, a side pressing shoe?

Mr. Sprague:—Not that I am aware of. I used wheels myself as long ago as eight years, on some experiments on the Third Avenue elevated, 34th street; but the ordinary sliding shoe is more satisfactory.

Mr. C. O. Mailloux:—I would like to have Mr. Sprague explain the difference, if any, in acceleration obtained with his system of multiple control, as compared with the ordinary control system. I have understood that there were advantages claimed for it, in so much that it enables the car to accelerate faster, or to reach its full speed sooner. This is a matter of extreme importance in rapid transit, such as would be suitable for an elevated road. I had occasion to study the matter two or three years ago when they first discussed the matter of equiping the road, and discovered, much to my surprise, though it might have been easily anticipated from theory that there are limitations to the average or schedule speed (in miles per hour) which it is possible to obtain on the elevated road, owing to the limitations of the velocity of acceleration. I was told at the time that Mr. Sprague was enabled to accelerate his cars faster, and that by being able to do so he was able to shorten slightly the schedule time between two stations.

Mr. Sprague:—I will give you an exact comparison. As to curves and grades the Manhattan elevated and the Brooklyn elevated are almost identical in their conditions, and require about the same energy per ton-mile for any given schedule. On a six-car train, a schedule of about 13½ miles an hour, when the train is loaded, is barely possible with a locomotive car weighing about 40 tons equipped with four motors of the largest size which are practical to put under a car. They would be rated at 600-horse power, but that is excessive rating, considering the thermal characteristics, and they could not stand the service. If instead of the proportion of weights on the drivers that that locomotive would give, these six cars are equipped, each car with two 80-horse power motors, it would be perfectly possible to go to a 16½ mile schedule, or if equipped with two 50-horse power motors, making the same aggregate motor capacity on a six-car train which it is possible to get with a locomotive car, a 15 mile schedule can be made with the distributed motor equipment, with identically the same power at the central station as would be required to make a schedule of 13½ miles with the 600-horse power localized on one car.

If the schedule of 13½ miles were only required with the distributed motors, there would be a reduction of about a million and a half dollars in the cost of delivering current to the car-shoe.

These are briefly the results of a good many calculations which have been made with reference to roads with these particular conditions. The reason is that there are three kinds of work; lifting of a car on an up-grade, which is independent of the schedule; simple traction, which is so much per ton, and is also perfectly independent of the schedule, except as the air pressure affects it; and inertia, which is put into a car and thrown away in braking. If you can get a car up to a certain speed, cut off the current, and then coast to a stop, it would be just as well to run the car that way as to go to some less speed, then run along at a constant speed, and coast without any braking to a stop. The energy put into a car for the purpose of getting up speed varies as the square of the speed, so that the difference in inertia energy between 20 and 25 miles is as 400 to 625. Under the conditions existing on the elevated railroads here and in Brooklyn, and for quite a range of schedules, the energy per ton-mile varies nearly as the cube of the schedule speed. It runs up rather rapidly. About the most economical speed with the existing station distances stops and grades is about 16 miles.

Mr. Boynton:—There have been so many criticisms on this paper that it is impossible to reply to them all in the short time that is left. I would say that I was much interested in Mr. Sprague's address on the subject, and have gained considerable information. I am not quite able to associate the multiple unit system of control with every condition of steam railroading. But there is no doubt that for most of the suburban conditions of traffic in cities it is applicable.

The traffic with which perhaps I have had more to do than any other is not exactly similar to suburban traffic. It is a traffic that does not consist of a great many trains running on frequent schedule. If one goes to a steam railway manager and proposes to equip a certain section of his line with electricity, one can tell him all the different methods of employing electrical apparatus, but he will inquire about dollars and cents. He will place that at the bottom of every proposition you bring up. If he has a million passengers to transport from one place to another in a year and you tell him that you can do it for considerably less than it is costing, then he will listen to what you have to say with interest. Nearly every one with whom I have come in contact in railroad business emphasizes that point. Of course it is the practical place to look. That is the principal reason why a sentence in the paper reads as follows: "It is considered probable that a given number of passengers can be transported cheaper with an electric locomotive hauling a train of idle cars, than if all the cars or two or three of them were motor cars." The probability is that the total weight of the train would be less. The above statement is merely an opinion, for no tests have ever been made of the two systems, where the trains are composed of standard steam railroad coaches. It would seem as if the locomotive train would be considerably lighter as it is relieved of the weight of many motors and equipments.

I differ slightly from Mr. Sprague in one other particular. Mr. Sprague remarked that he did not think that electric traction would take place under what are now known as steam railway conditions; that is, it will not take place in the future under existing steam railway methods. I think it will have to begin in that way and perhaps gradually develop into a multiple unit system afterwards if traffic warrants it. There are a number of roads that are running under steam railway conditions; electric trains and steam trains running on the same track; with sometimes only two minutes leeway between the electric and the steam trains. A practical point brought out by one or two speakers, that the service should require no time table, is a very important point. If the trains run at regular intervals, like 5, 10, or 15 minutes headway, no time table is necessary then, and the public appreciates it.

The use of storage batteries is undoubtedly going to increase. It is going to increase in more than one way. I have spoken of a road that is run without feeders. We are at present installing a storage battery on the end of the road, connecting it right across the end of the line. The train service is such that that battery can be kept fully charged by utilizing the current when no trains are on that end of the line. Its tendency is of course to even up the potential along the line. Such a method of feeding a railroad, if you choose, is much cheaper as regards first cost than putting in a feeder of metal.

In regard to some of the other criticisms, I am obliged to Mr. Pope for clearing up the title of the paper. The object in writing it was simply to bring out a discussion of various points. As to some of the figures in the paper, I did not think it was necessary to add a foot note to the effect that an employee of a corporation, such as I am, is not always allowed to give out exact figures. Therefore, if I said from four to six kilowatt hours per train mile, and the actual figures obtained from tests with a wattmeter, voltmeter and ammeter on a train was 5.1; I prefer to say four to six instead of 5.1, and by carefully reading certain parts of the paper, it will be seen that the length and weight of the trains, under consideration are stated with sufficient clearness. When it is said that power stations are built for $80 or $90 a kilowatt, perhaps I might say that I have seen one built for $88—a large one at that, within three years.

MR. SPRAGUE:—I did not mean to say that the multiple unit system was the one system applicable to *all* conditions of railway work. A great many conditions must necessarily be met in specific cases. What I had more particularly in mind was the handling of suburban passenger service, which is the first elemental step from trolleys into steam railroad fields, and also I would not have it understood that I do not believe in the thorough practicability of operating steam cars over the same tracks as electrics. I have had 50 of each on the same tracks.

MR. RIES:—I should like to have Mr. Boynton inform us if he will, as to the frequency of the train service on the particular line which he refers to, and of which he has charge. That is to say, how many trains are actually driven from the generating station at the same time, whether there is any lull worth speaking of between them, or whether the schedule is so arranged that the generating station has a practically constant load upon it at all times. That would throw some considerable light on the subject of the advantage on the line in question, of the train unit operations, that is, as to the relative merits of individual small units or long train units.

MR. BOYNTON:—I would state that I have a general supervision of several lines, and they are all different. The heaviest one, and the one that carries the most passengers, is perhaps more referred to than others. The train service on that line is half hourly, and to reduce it to the basis of the paper it means a half-hour train from each end of a 10-mile run passing in the middle. But there are other portions of the road dependent upon the same power station, so that in the summer, with the electric heaters off, the load will vary perhaps from 200 amperes, which practically means one train, to 800, which practically means four trains, and of course the starting of that number of trains will run this up considerably higher for a few moments. Mr. Pope and others have mentioned the subject of ice on the rail, and it is with us a most important subject, and I think to almost all railroads using this kind of a rail. Ordinary sleet, the shoes and stiff wire brushes will scrape off; there is no doubt about that. But there is a kind of sleet which I tried to describe in the paper (perhaps I did not succeed), which we will call a coat of varnish, and you cannot get it off with an ax. You can chop it, and do anything you please to it, and it sticks like a brother. Nothing will move it, apparently, until the temperature changes and it loosens up, and if I am not mistaken, some of our elevated roads this winter have been tied up more than once from that very cause. Take that kind of ice and strike it with a knife or an ax, and you make a slot across it, which shows just where the edge struck it. Strike it in half a dozen other places, and you make half a dozen marks, and the sleet between the marks is stuck just as tight as it was before, and that is the kind of sleet which is hard to remove. Sleet that you can strike a blow, and it will fly off, gives no trouble. Upon such questions as this depends the successful operation of the road, and when the weather or some other unforseen circumstance ties up the road for a few hours, it is rather humiliating, to say the least.

I have recently been experimenting on methods of removing sleet from the track, using various substances upon the contact surface of the rail to prevent the ice from sticking to it, no matter what the temperature is. I have seen the railroad freeze up in five minutes when it was raining. I have seen a car go through and the next car behind it was stopped. I have recently tried a piece of tool steel consisting of a plate three-quarters of an inch thick and perhaps ten inches square, sliding in grooves, controlled by a lever, by which you can push the plate down on the top of the rail in a vertical position. As far as we have tested such a thing it takes everything off the rail, almost including a chip off the steel rail, and it keeps itself sharp, so that it looks as if the problem was pretty nearly solved; but there are certain matters that have to be perfected, for instance, it is almost absolutely necessary to slide the plate vertically, just as near the vertical as you dare, and then it will cut and will keep itself sharp, but if it is back of the vertical it loses a good deal of its cutting power, and it must also be so arranged that when it strikes a joint or a break in the rail, it can back off and jump over and come forward again, which can be done by means of powerful springs. Those little points seem unimportant, but they are vital in running a road, and I am not aware that they have been solved yet.

[Adjourned.]

DISCUSSION AT CHICAGO, FEBRUARY 28, 1900.

MR. BION J. ARNOLD:—We recognize in Mr. Boynton's paper a careful analysis of the relative advantages of steam and electric traction, and a concise digest of the present practice in constant potential direct current railway work. Inasmuch as the paper gives the results of Mr. Boynton's experience on a heavy direct current line, it is of special interest and benefit to electrical engineers, and should be to railway officials contemplating the equipment of their lines electrically.

However, owing to the present state of transition, being as we are, between the direct current road and the alternating current road, it is hardly safe for any one to take a positive stand and assume that we are going to confine ourselves in the future to a direct current road. Mr. Boynton's paper seems to point out many difficulties for which he is seeking solutions, that would not be present in case the alternating system were adopted. I refer especially to rail bonding; to the question of working conductors, and the feeder system. It is possible that in the near future we shall see the direct current largely abandoned for new construction, and our long distance roads operating with alternating motors, probably at much higher voltages than at present seem practicable. In fact, it seems essential to increase the trolley voltage, if we are going to handle the heavy trains mentioned by Mr. Boynton, at high average speeds. When we consider that in order to make an average speed of 45 miles an hour with a train weighing 100 tons, stopping an average of once every three miles, it requires a maximum capacity of 1600-horse power on each train, it will readily be seen that the amount of current at 700 volts becomes greater than can be carried by any reasonable amount of copper, and by any known means of contact shoes or trolley wheels. This also applies to the bonding of the rails. For this reason the only practicable way is to increase the voltage of the working conductors, thus cutting down the current, and the cost of transmission lines.

Regarding the cars, it occurs to me that the most probable solution will be the adoption of heavy cars for through traffic, equipped with motors designed especially for long runs and few stops, and lighter cars for the local or feeder service; this being practically the style of equipment that is adopted by steam railroads for similar work. Each car would be a motor car in itself. If the heavy train should ever be used for high average speed, and numerous stops, it seems necessary to equip each axle of each car with motors, for the reason that it is impossible to get sufficient adhesion to accelerate the train rapidly from but two pairs of traction wheels on each car.

MR. R. H. PIERCE:—I agree with Mr. Arnold that this paper is most interesting as showing the present state of the art; but it seems extremely doubtful if it will enable us to draw any general conclusions as to what will be done in the near future in electrical railroading.

In figuring over a number of propositions where it has been proposed to use electricity for heavy trains at a high rate of speed, I have always been forced to the conclusion that it was economical to resort to polyphase transmission for distances considerably less than 10 or 12 miles. I believe in most cases we will reach the limit at about one-half that distance. The distance at which you can transmit with direct current in many cases is shortened up by grades which call for heavy current, in cases like those mentioned by Mr. Boynton, or even those mentioned by Mr. Arnold. Of course in each special case the distance at which it is economical to transmit with a direct current depends upon the grades, and also upon the cost of producing power in that locality.

Although it is true as Mr. Boynton says that up to the present time it has been impossible to operate trains with alternating current motors, it seems as if the possibility of a solution of this problem in the near future ought to be considered in designing an electric road of this kind; and I am inclined to believe that the equipment of a road to-day with polyphase generators of low frequency may be considered a conservative step in view of the possible, and not improbable, developments of the alternating current motor in the near future. Of course such a system at present would mean the use of sub-stations with rotary transformers, as referred to by Mr. Boynton.

Inasmuch as I stand in Mr. Boynton's place here this evening it is hardly becoming in me to criticise any of his statements, but it would seem as if there might be a difference of opinion on some of his conclusions as to the best methods of obtaining certain results. In speaking of the matter of feeders, he comes to the conclusion that steel is cheaper and more satisfactory. I doubt if experience has shown this to be so. Where steel has been used for feeders in the past, second-hand rails have frequently been used, and when you consider the difficulty of bonding these, as fully explained by Mr. Boynton, it is evident that these rail circuits have been very poor conductors. There seems to be a great scarcity of data on this subject. I note that one of the leading authorities assumes that a steel rail will have a conductivity of one-sixth that of copper, of equal weight; and this figure has often been taken for granted by railroad men. I note, however, that in a paper which was read not long ago before the Institution of Electrical Engineers of Great Britain the figures showed that the conductivity of steel was in many cases, only one-tenth or one-twelfth that of copper. When the resistance of the bond is taken into consideration and the cost of bonding, which Mr. Boynton says is $2 a joint for heavy bonding, I think it probable that many of the steel circuits which have been put up, have proven more expensive than copper would have been. At the present market price it seems that aluminium is cheaper than copper, and probably cheaper than steel.

In regard to the electric lighting of stations, it seems to me that an enterprising electric light company could furnish a satisfactory light cheaper than the railroad company could do it by the method shown here. This method contemplates the use of 120 volts for lighting, and the throwing away of the difference between that and about 700 volts in resistance, which would make an efficiency of only about 20 per cent., discarding the loss in the battery, and at the same time calling for an investment of $900 on a 60-light plant which would be an investment of about $300 per kilowatt. There are other successful ways of producing cheap lights at present.

This reminds me of one case where a station agent very carefully figured out how much he could save over the use of gas by purchasing electric light from a local company. He sent his report in to headquarters, and was informed that after figuring it over they had come to the conclusion that he could save still more by burning kerosene, and therefore he should discontinue the use of gas.

Mr. Geo. M. Mayer :—I move a vote of thanks to Mr. Boynton for his very able, instructive and interesting paper.

Motion carried unanimously, and the meeting adjourned.

[Communicated after Adjournment by M. H. Gerry, Jr.]

The paper of Mr. E. C. Boynton contains much interesting information, and is a valuable addition to the literature of this snbject. Its title, however, suggests to the writer the pertinent question, which has often occurred to him in considering electric traction problems, whether it is well to follow too closely the precedents established by practice in railroading under the present steam *locomotive* conditions. Certainly, practice long established and demonstrated as correct, should not be lightly cast aside without good reason, but in this case it is well also to consider the changed conditions which electric power introduces.

Modern railroading is the result of a vast amount of practical experience in adapting *direct steam power* to the economical transportation of freight and passengers. It is both interesting and instructive, however, to remember that the early attempts at steam locomotion were in the line of traction engines, and were directed to adapting the new motive power to common roads and wagon conditions. Even after steam was applied to the early tramways, we can trace from the old prints the natural attempt to adapt the stage coach to the new order of things.

Everyone is familiar with the later metamorphose of the street railway. We have seen the small horse car, without trucks, and running on light flat rails, pass away, and its place taken by the modern electric car on the heavy track construction of to-day. The new motive power made possible a desirable change in operating conditions in the direction of better and more efficient service, and this in turn, has had its effect, and has extended the business to its present vast proportions. This development has been due, not to a saving of so much per car mile, but to the greatly increased traffic resulting from the better and faster service.

All this applies to steam railways in a certain degree. The traffic on many lines is becoming congested at times, and there is an ever-increasing demand for faster service both for freight and passengers. The speed of all freight trains and the number of *fast freight* trains in service has increased enormously in late years, and there is an ever growing demand for such service, as railway traffic-men know. To meet these conditions the railroads are adopting very heavy locomotives in order to obtain sufficient power and traction, and have been further forced to reduce the weight of their fast passenger and freight trains. Now, this sacrifices economy, because in operating under *locomotive* conditions the heaviest train is always the cheapest train. Speed, however, is demanded, and it is impossible to obtain locomotives of sufficient power and traction to haul the heavy trains at high speeds. Even if locomotives of vastly greater weight and power could be obtained, and the track and bridges made sufficiently strong to support them, still a point in speed is soon reached when the weight hauled behind the locomotive becomes too small to be profitably handled ; that is, the weight of the locomotive and tender becomes abnormally great, compared with the train. It is possible to obtain from steam locomotives, about any practicable speed (seventy or eighty miles are common enough), but the difficulty is to accelerate and haul a train of sufficient weight to make it pay. Here we reach the limit of profitable speed with locomotive power.

The entire weight of engine and tender is of course dead load, and in fast service becomes of great importance. The writer averaged the train weights, the engine and tender weights, and the speeds from the fastest passenger train in service on each of ten representative American roads, and found the average speed at about forty miles per hour, and the locomotive and tender weights about forty per cent. of the weight of the train behind the tender. In special fast mail service, and sometimes in suburban passenger service, the percentage is even greater. The writer called especial attention to this matter of locomotive traction and dead weight in a paper before this INSTITUTE in 1897.*

Another consideration of importance is the accepted fact among railroad men that to successfully handle a large number of trains, it is essential to keep the average speed nearly the same ; the greater the number of trains, the more important this

*TRANSACTIONS, 1897, vol. xiv., p. 353.

becomes. Hence, of late years there has been a general speeding up of all trains, and this speed problem is one of the most serious which railroad men have to face.

Now, what relation has the above to the question of electric motive power? Just this, that there is a call at the present time for an improved service, and that it is becoming more and more difficult with steam locomotives to keep pace with the ever-increasing demands of railway transportation. Hence, there is a field for electrical motive power, in a direction where it is known to have great advantages.

Electrical traction means centralization of the power generating machinery. The more this centralization takes place, the greater the advantage. Electrical transmission has developed until fifty or sixty miles is an entirely practicable distance for transmitting power. Thus the generating stations may be from one hundred to one hundred and twenty miles apart, and this distance is sufficient for all practical purposes. The chief difficulty is not now in generating or transmitting the power as alternating current, but in its utilization in railway motors. To make use of direct current motors, involves the establishment of rotary-converter sub-stations, and this not only introduces serious complications, but it counteracts to a material extent, the advantages gained by long distance transmission. The first great need at this time, in connection with the introduction of electric power on long railway lines, is the adaptation of the alternating motor to this service. That this can be done the writer has no doubt whatever. The subject has not had the wide consideration which it merits, in view of the possibilities it would open up for the introduction of electric motive power. There seems to be quite a general impression among engineers who have not especially considered the matter, that there is some inherent reason why an alternating current motor cannot be used. Such impressions are erroneous. The induction motor has simply not been especially developed in this line. It is certainly about the best all-around motor for power purposes, and by virtue of its remarkable simplicity and other desirable qualities, it is especially fitted for the heavier and faster railway service. The double conductor required is not a serious objection, except, perhaps, on overhead trolley lines. An induction motor is, in many respects, a much more flexible machine than the ordinary series railway motor, and it can be so designed as to give a better form of speed and torque curve for most kinds of railway service. There are difficulties in the matter of control, but they are relatively less than those which have been more or less successfully met in the case of the series direct current motor. It should be borne in mind that the induction motor has been developed thus far as a stationary motor with special view to obtaining constant speed, high efficiency and high power factor. To adapt the inductive motor to railway purposes, will of course require a considerable amount of development work, but in view of the great benefits to be derived, it would seem to be justified. Whenever the alternating current motor is perfected for railway work, all the other problems in connection with the transmission and distribution of power through the transformers can be quite readily solved.

In regard to the methods of applying the motors to the train, the writer holds to the opinion that for general purposes the *locomotive* construction should be abandoned, and the motors placed on the cars (preferably on every car, but not necessarily so), and controlled from the head of the train. This is both theoretically and practically the best method, and will especially apply to the railway conditions mentioned in the first part of this discussion. Railway motors may yet be as simple as air-brake apparatus, and when this comes there will be a great development in applying electric power to standard railways. It is the alternating current motor that we need now.

If electric power is ever applied largely to standard railways the writer fully believes it will work a revolution in railway methods, and that there will be a decided change in the design of rolling stock. Such great and important changes must come slowly, still the general adoption of electric motors may not be as far off as we suppose at this time.

Helena, Mont., March, 1900.

[Communicated After Adjournment by Carl Kinsley.]

In common with all those who have occasion to compare capacities, I am exceedingly interested in the method proposed by Dr. Pupin. Since the time of Maxwell we have understood that absorption is due to the heterogenous nature of the dielectric, but the measurement of the capacity where we have such a dielectric, as for instance, long cables, is difficult and the results still uncertain. The apparatus exhibited was connected as used by the Gott method of measuring capacity when a direct current is employed. This has been found to be probably the most satisfactory of the many possible methods when there is trouble with absorption and leakage. But instead of using a sine wave such as Dr. Rowland (*Philosophical Magazine*, January, 1898) used with his dynamometer zero power methods, an induction coil is employed which gives a wave rich in overtones. The effect of absorption can be expressed by assuming a resistance in series with the condenser. How largely this depends on the period was shown by Dr. Penniman, (*Philosophical Magazine*, January, 1898, p. 70) who found in one case at a frequency of 14.0 complete periods per second an apparent resistance of 139.6 ohms, while at a frequency of 131.1 the apparent resistance was only 5.2 ohms. The importance therefore of knowing the exact periodicity of the current used and of having a high period is apparent.

When the Gott method of measuring capacity is used, the effect of both absorption and leakage is to increase the apparent capacity. The standard, a mica condenser, has negligibly small absorption. The longer the interval of charge is taken the greater becomes this apparent increase of capacity. This is strikingly shown in the case of the following cable, which is entirely typical. Two rubber insulated wires of the cable were used. Their insulation resistance was high. About one-half mile was unarmored and trenched, while one-half mile, which was armored, was lying in New York harbor. The lowest capacity was obtained by a buzzer and telephone. In the second observation the interval was estimated at one-fourth second, the charging key being merely tapped to close the circuit, while the galvanometer remained connected.

From the shape of the curve it is seen that when the time interval is small it must be determined accurately. With commercial condensers of the beeswax-rosin type, the variation of apparent capacity with time of charge is not so pronounced. Certain ones that are rated at one-third microfarad each show that value after a five seconds charge while after a one-fourth second charge their value is 0.292 M.F. and with a buzzer 0.287 M.F.

For scientific accuracy the electromotive force should be a sine function of known period.

When the capacity of cables and condensers for telegraph service is to be determined, the measurement with an alternating

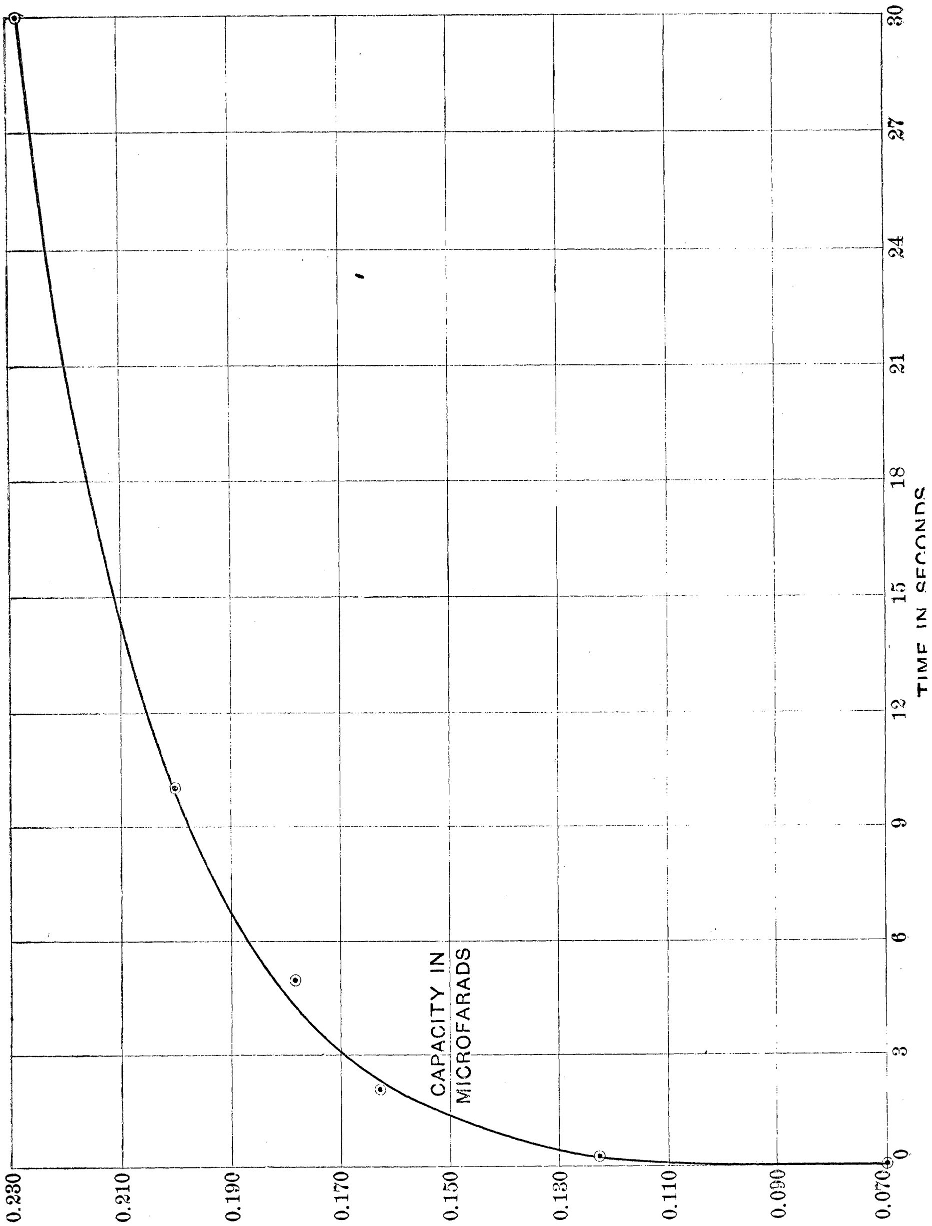

FIG. 3.—Capacity of Cable with Varying Time of Charging.

current will not give the value that must be used in calculations. Uni-directional charging for a suitable time interval will give better values. Possibly there exists a definite relation between the values obtained by alternating, and those usually found with direct current charging. A careful correlation of the various empirical methods heretofore used and the proposed alternating current methods of measuring capacities would be of great value to both the practical engineer and the laboratory experimenter.

The actual capacity changes but little, if at all, with a change of frequency. In commercial condensers (on alternating current circuits) the heating is usually caused by the absorption. Rosa and Swith (*Physical Review*, January, 1899) came to that conclusion though they quoted Boucherot (*L'Eclairage Electrique*, February 12, 1898) who found that the leakage current alone was responsible. In faulty cables it is quite probable that a good deal of energy will be dissipated by the leakage current. This would have the effect of resistance in parallel with the capacity and it will be unaffected by the periodicity of the current. It may be possible to separate the apparent resistance of absorption from the dielectric resistance by varying the frequency. The alternating current method is the only one that can be used when there is bad leakage. With a buzzer, for instance, when even 5000 ohms of non-inductive resistance is bridged across the cable terminals, already mentioned, the capacity rose to 0.075 M.F. instead of the 0.070 found with the high insulation resistance. No direct current method could be used at all under those trying conditions. The great value of the proposed method of determining the capacity is shown by the preceding illustration and it should be made one of the regular methods for making such measurements.

Governor's Island,
N. Y. Harbor, March, 1900.