Engineering Problems
in
Electric Elevated and Suburban Railroading

The Multiple Unit System

BY

FRANK J. SPRAGUE

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DELIVERED BEFORE THE
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HISTORY AND DEVELOPMENT OF ELECTRIC TRAIN OPERATION

In May, 1887 ~~1897~~, a contract was signed for installing in the City of Richmond, Virginia, an electric railway which marked the active beginning of the modern development, for it proved to be the pioneer in most all the essentials of the present trolley system. It was not a long contract, but its terms were somewhat remarkable, being dictated by enthusiasm and self-confidence rather than by ordinary commercial rules.

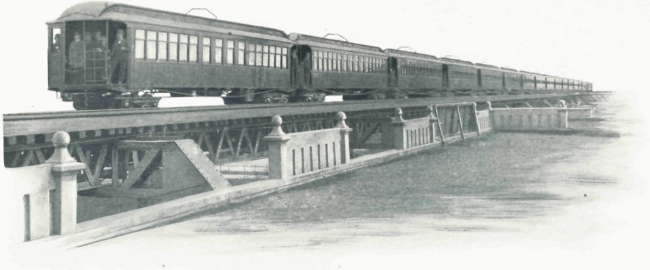
It provided that a system, existing then only on a blue-print, except that the general motor ideas had been experimentally developed on the 34th Street branch of the Manhattan Elevated Railroad, on an unbuilt road eleven miles in length, with twenty-nine curves, straight grades as high as 8 per cent., and grades on curves equivalent to 12 per cent., embracing a central station of 300 H. P., and equipments for forty cars, should be installed in ninety days, and for this $120,000 in cash was to be paid if the system "was satisfactory to the Railway Company."

The net loss to the Sprague Electric Railway & Motor Company on this contract was fully $100,000. The rest is history—the history of an unprecedented industrial development of such a character that every individual connected with the Richmond Road through all its vicissitudes may well take a personal pride in it.

According to statistics published in the *Street Railway Journal* in February, 1899, by the close of 1898 there was in operation in the United States alone, out of a total of 17,291 miles of electric cable and horse car tracks, 15,672 miles with electrical equipment, comprising 36,429 motor cars and 7,914 trail cars.

The capitalized liabilities of these electric roads were close on to $1,500,000,000.

Ten years later, in May, 1897, another contract was signed, this time individually, for replacing the operative steam equipment on the South Side Elevated Railroad of Chicago by an electrical equipment on a new method, which, if successful, was destined to mark the abolition of steam and locomotive systems of any character on urban, interurban and suburban traffic, the next great field of electric railway development.



SPRAGUE MULTIPLE UNIT TRAIN OF 13 CARS

This contract was something like the other. The commercial conditions were onerous, and the professional and financial risks were great, such as might well make at least the officials and engineers of the road gravely hesitate, for the multiple unit system, absolutely untried in commercial practice, had to be reduced to practical operation on a scale of development and under conditions never before attempted in electric railroading even in Richmond.

It may well be asked: What was the warrant—what the necessity of such a contract? The answer is based primarily on the fact that rapid transit is the science of competitive railroading, and if by wheeled vehicles, ultimately reduces to a question of the proportion of weight upon the driving wheels.

All other matters entering into the question for any given case and set of conditions, such as schedule speed, traffic capacity, extent of equipment, total investment, frequency of service, operating cost, and even safety and reliability of service, are incidental to and directly or indirectly dependent upon the adhesion of the driving wheels of the vehicles to the track.

The fastest possible car movement between stations can always, under equal conditions of equipment, load, grade and power supply, be made by the vehicle which has the greatest percentage of weight on the drivers.

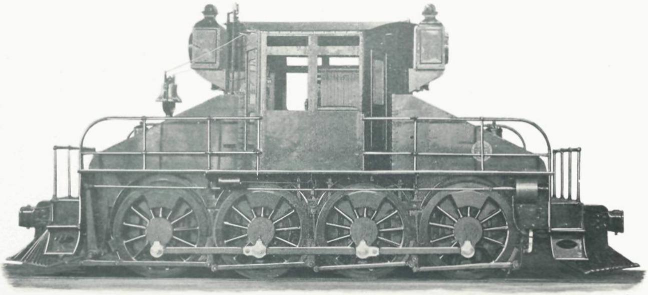
Therefore definite theoretical and practical limits exist for railroad schedule speeds under any given conditions, and the highest schedules in any case can only be made by a train system which preserves under all circumstances the specific characteristics of a motor vehicle with 100 per cent weight on the drivers.

This system broadly includes all modern street railways.

The second is the locomotive system, following steam precedents, and dictated by the limitations of steam engineering, in which there is concentrated in a single unit the weight and power necessary to handle a train under given conditions. This locomotive idea has taken two forms, one of which copies one or other of the many types of steam locomotives, with such modifications as are permissible with electric motors, but which, despite the remarkable general progress of electric railways, still finds comparatively few applications in actual practice.

Notable among these are the B. & O. tunnel locomotives in Baltimore, and the proposed equipment for the Central London Railway.

Among the earliest, if not the first of the large locomotives, is one of 1,000 H. P. capacity, built by the writer



1,000 H. P. 60 TON ELECTRIC LOCOMOTIVE, BUILT IN 1892-4 BY SPRAGUE, DUNCAN & HUTCHINSON

and his associates for the North American Co. about seven years ago.

In the present stage of development of Rapid Transit Systems for urban, surburban and inter-urban service, where stations are close together, traffic much congested morning and evening, and yard and terminal facilities limited and costly, high schedule speeds are absolutely essential. How shall they be had?

There are three distinct and generic methods of railroad passenger transportation as follows:

The single car, operating independently.

The locomotive, pulling trail cars.

The multiple unit system, or aggregation of transportations units, each fully equipped, into trains, and provided with a secondary control.

The first received its great impulse at Richmond in 1887-8. Its history and characteristics, as illustrated by the tens of thousands of cars in daily operation need no detail description.

Each car is a motor unit, with large effective driving weight, from 80 per cent. to 100 per cent., equipped with hand control, but incapable of aggregation into trains with localized control.

Another form of the locomotive may be described as the locomotive car, which consists of a car body of the usual form, arranged to carry passengers, with one or both trucks equipped with motors, and hence with the weight distributed over a considerable distance, and with, as in the other case, hand control provided at either end of the car.

Such a one was experimented with by the writer on the 34th Street branch of the Manhattan Elevated in 1886-7, where was used the first modern railway motor, and a special car was built about the same time which was to have had an equipment of two 75 H. P. motors on each truck. This was before the days when the Richmond road was built, and therefore before the modern advance in electric railroading.

This type of locomotive car was used in the Intramural Railroad in Chicago during the World's Fair, and is now in operation on the Metropolitan and Lake Street Elevated Railways in Chicago.

A modification of this locomotive car plan has been more recently proposed, which consists in putting a locomotive car at each end of the train, passing the main circuits through all the other cars, and providing duplicate hand controls at each end of each locomotive car for the eight motors constituting their equipment.

The system is absolutely untried, presents innumerable difficulties, and has about all of the defects of the locomotive system, but constitutes an acknowledgment of the necessity of greater weight on drivers and greater power for meeting the requirements of modern transportation.

In matters of transportation, the passenger's demand and the wishes of an operating manager are not always alike. The passenger requires for his convenience the most frequent time intervals, the shortest station waits, and the highest possible schedule speed. The railway manager is apt to concentrate loads, increase the time intervals, and let the passenger wait, but in so doing he may lose the passenger.

With a locomotive car system this is the inevitable result, because otherwise the entire motive equipment would be kept in continuous operation at low economy and at great expense.

All these methods—the single car, the locomotive, the locomotive car and the doubling up of locomotive cars—fall short of meeting the requirements of a flexible railway system to be operated on a high schedule.

The single high-powered car, using all of its weight on the drivers, needs no commentary so far as ordinary application is concerned, but the methods proposed for the aggregation of cars and the handling of trains through the medium of a locomotive or locomotive car, or aggregation of hand-controlled locomotives occcupying fixed positions, utterly ignore the possibilties of electric application,

95 TON ELECTRIC LOCOMOTIVE, BUILT IN 1895 BY GENERAL ELECTRIC COMPANY

and the advantages manifest in every car operated on the street.

In some form or other this has been recognized for a number of years, and it occurred to a number of engineers that, for increased adhesion and to provide more power with distributed weight motors, could be distributed throughout the train, the mains carried through it, and the system governed by a controller at the leading end.

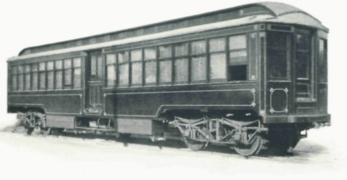
One of the earliest of these proposals was made before the Society of Arts, in Boston, in 1885, just prior to conducting experiments on the Elevated Railroad, at which time I contemplated the use of motors on each car, or every other car, and a pilot locomotive or car containing an adjustible controlling apparatus which could be made effective for handling one or more cars. This project, however, never reached fruition, and of course fell short of the possibilties.

Much more seemed certainly feasible. The excuse for the last mentioned proposal is found in the evident engineering truth that if greater power is applied to a train, and a high percentage of the weight on the drivers utilized during acceleration higher schedules with reduced strains are possible.

Considering for a moment a single car as a unit, and putting all the available power in the motors connected to each of the axles which space permits, it is readily possible to put on a motor equipment which will develop over 20 H. P. per ton moved, and to use 100 per cent. of the weight on the drivers. The possibilties of this unit, that is using the entire weight of the car for traction, and all the power which can be put within the space permitted, is the limit, and absolutely the only limit of the possibility of the speed to be attained by an electric car.

If now this unit is lengthened, that is cars aggregated into a train, and the same ratio of weight on the drivers and the same H. P. per ton is maintained, then it matters not what the length of the unit, identically the same schedules can be made with the train as with the single car.

The most effective train operation, however, requires something more than schedule speed, and it seemed that



FIRST LOCOMOTIVE CAR, BUILT IN 1886 BY SPRAGUE ELECTRIC RAILWAY & MOTOR COMPANY

considered from a competitive standpoint, and with the idea of gathering every passenger possible, the proper method of operating a railroad should be something as follows:

Starting at the time of least traffic, to operate the smallest allowable unit at intervals determined by the ratio of the increased cost of operation to the increase of passenger receipts to be obtained by shortening the interval. Then, as traffic increases, to shorten up this time interval as far as is consistent with safety, then to increase the size of train unit while maintaining the same interval and high schedule to take care of the greater traffic.

It is said that smaller train units cost more to operate than larger ones. This is to a certain extent true, but against this is the simple fact that on the scale of wages paid on many railroads the difference in total cost between operating two two-car trains and one four-car train is one passenger per car for every fifty stations as spaced on the elevated railroads in New York.

In view of this fact it can hardly be questioned that if shorter intervals are made possible then more passengers would be gathered than represented by these differences, and trains would, if a practical system were devised, be operated in any length from one car up.

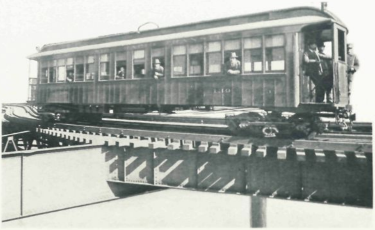
These, I think I may fairly say, were the views which finally came to be held by such transportation authorities as Chief Engineer Wallace, of the Illinois Central Railroad, and Chief Engineer Cornell, of the Brooklyn Elevated, in the spring of 1897, and in this connection it is interesting to note a chronological review of various proposals which had from time to time been made for elevated railroad equipment and operation, which is appended to this paper, which will serve to illustrate a diversity of ideas and recommendations which have done much to bring ridicule upon the professions of electrical engineers.

This review is not intended to give a complete or detailed history of electric railway development, but is a running commentary on a variety of proposals made for train operation on elevated or suburban railroads from the year 1880 to the present time.

A survey of this record for the first seventeen years, up to and including the first proposals made as late as the spring of 1897 to the South Side road, shows that with the exception of offers made by me at various times, beginning at the Society of Arts, in Boston, in 1885, and ending in definite proposals to the Manhattan Elevated Railway in 1896 and 1897, and later, there were no propositions, or even a suggestion, from any manufacturing corporation or individual to equip a railroad on any other than a locomotive or locomotive car plan, with the single exception that on the Liverpool Overhead Railway two car trains are operated as a unit, each unit having a motor disposed at the leading and back ends, and with a hand controller at each end.

Typical important installations were, on the locomotive plan pure and simple, in 1895 at Baltimore, and on the locomotive car plan, under the supervision of Mr. W. E. Baker, on the Intramural road at the World's Fair in Chicago, in 1893, and on the Metropolitan West Side Elevated Railroad under the same supervision in 1895, at the former of which Mr. Baker had to override recommendations in favor of a locomotive.

The variety of ideas indicated by these notes, and the inexcusably wide divergence of expression concerning the commonest engineering facts, as well as the crudeness of many electric railway proposals, was never more sharply shown than in a paper by Mr. Wallace, of the Illinois Central Railroad, on the subject of "The Substitution of Electricity for Steam as a Motive Power for Suburban Traffic,"



FIRST SPRAGUE CAR ON SOUTH SIDE ELEVATED RAILWAY—APRIL, 1898

before the American Institute of Civil Engineers, February 3, 1897, and in the discussion which followed it.

Mr. Wallace, having, in December, 1891, been directed by the management of the Illinois Central Railroad, of which he was then the Chief Engineer, to investigate the subject of adopting electricity on the Illinois Central Suburban Railroad, after a careful consideration of the requirements of the road, issued a list of forty-five categorical questions covering the operation of a fairly fixed equipment at twenty miles an hour. These questions were sent to all the various electrical companies except the Sprague, which had at that time been absorbed by the Edison General Electric Company. Consequently, for the old Sprague Company and for myself I must disclaim any responsibility for the variety of results.

I will not attempt to review the answers to all the inquiries as presented by Mr. Wallace, only touching upon a few of them to illustrate the disparity of recommendations made, but for an interesting detail comparison refer to the comments at the meeting by Mr. Charles Henry Davis, from Mr. Wallace, partly quoting, that: "The engineers giving this matter their attention have been enthusiastic electricians; they have seldom been practical or expert mechanics, and the writer would add, usually inexperienced as railroad engineers."

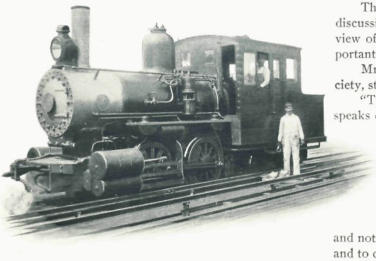
But let us briefly take note of the recommendations.

The motor capacity varied from 100 H. P. divided into four units, to 200 H.P. divided into two units, and distributed from one to two motors on each of two trucks under a locomotive car carrying passengers, or on the other hand aggregated into a locomotive pure and simple without passenger carrying capacity.

Both ring and drum armature constructions were recommended, and driving wheels of from 30" to 42" diameter.

About every possible form of axle driving, except chain or belt transmission, was proposed. One company was indifferent as to whether the motors were directly on the axles, or gear transmission was adopted; another recommended spur gearing; another, cranks and parallel rods; and still another no form of gearing under any circumstances, but an armature mounted on a hollow shaft surrounding the axle.

The central station equipment varied from 4,800 to 18,000 H. P., and the steam units from 400 H. P., driving single machines, to 1,500 H. P. driving double machines.



28 TON BALDWIN LOCOMOTIVE, SOUTH SIDE ELEVATED RAILWAY—ABANDONED JULY, 1898

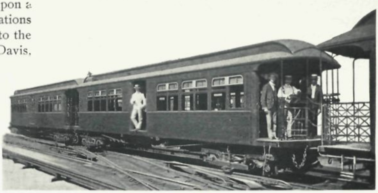
Horizontal compound and vertical triples had their advocates, and rope or belt as well as direct connections between engines and dynamos.

The space required for the central station varied from 12,000 to 75,000 square feet, and the cost of power plant, not including real estate or buildings, from $320,000 to $1,169,000.

Amount of fuel required per H. P. from two to three one-half pounds.

The annual cost of power plant operation ran from $60,000 to $225,000.

The potential varied from 500 to 1,000 volts.



TWO CAR MULTIPLE UNIT TRAIN ON BROOKLYN ELEVATED RAILROAD—1898

The cost of trolley lines and feed wires from $40,000 to $172,000, and repairs to the same and other line expenses from nothing to $23.50 a day.

The practical curvatures from "50-foot circle" to "150 feet radius."

On one subject there was unanimity of agreement, the transmission was to be by continuous current, and by overhead trolley. Despite Mr. Wallace's request for information about a third rail supply, it was incontinently waived aside.

The multiple unit system was not in any form proposed, but there was discussion on the subject of the relative advantages of small independent units versus trains.

The recommendations made hardly need extended comment, and one can well imagine the reasons which stopped any then further action on the part of the Illinois Central Railroad.

The whole paper is one of great interest, but from the discussion I will extract only a few comments which in view of the immediate subsequent developments are important.

Mr. Thomas C. Clarke, the Past-President of the Society, stated as follows:

"The author, under the head of 'minor problems,' speaks of 'the size of transportation units and whether independent motors of large power shall be used to haul long trains of trailers, or whether small transportation units, run at more frequent intervals, shall be adopted, with motors on the cars. In designing the rolling stock and structure of elevated electric railways in cities, this is the main point, and not one of minor consideration. Neglect to study this and to come to the correct conclusion had led to the financial failure of one of the largest electric elevated railways that has been constructed, and will lead to the financial failure of all others that follow the same lines.

"Carrying passengers in a city does not differ from any other business. The first requisite is to get abundant traffic; the second, to handle it with economy.

"Elevated lines run in competition with surface lines, and charge the same fare. The surface lines can beat them in all points but one. They afford more frequent stops; there is no climbing of stairs; cost of construction and, consequently, interest is less, and the system of transfers to branch lines is a great accommodation to the public. The elevated trains, not being impeded by surface traffic, can make better time; but for that, no person would ride in them, except to escape crowding.

"Common sense would indicate that the managers of elevated lines should try to approach, so far as possible, the conditions which have made surface lines a success.

"Frequent stops can only be attained, without losing too much time, by having a great power of acceleration. Any amount of power can be sent from the central reservoir, but if the wheels of the car slip, a limit is reached. Therefore, instead of having only one-third of the weight of the train available for adhesion, as is the case where an electric locomotive draws a train of trailers, utilize the whole weight of the train and passengers by putting motors on every car, connected electrically and mechanically, and worked by a motorman at one end of the train. Another advantage resulting from this is that gradients can be steepened, and the height of the station and their stairways reduced.

"If, in addition to this, short trains of light cars are used, the weight and cost of the structure can be greatly reduced, and the interest charges also. Small trains mean frequent trains to enable the traffic to be carried, and everybody knows there is no means of attracting traffic so powerful as that of frequent trains, as there is then no waiting at stations, which everybody hates.

"The summing up of the whole matter is, that to make city elevated railway a success, the surface electric system must be copied, and placed above obstructions from other traffic, and not the steam locomotive system of long trains at greater intervals.

"The process of evolution which develops everything along the fittest lines will make the city elevated railway of the future one of light structure, carrying light and very frequent trains, with motors on the cars themselves—a development of street trolley lines, and not of steam locomotive railroads."

Mr. Walter H. Knight stated that: "The whole object of the elevated railroad is speed, and speed cannot be made with short headways. It would make little difference, so far as speed is concerned, whether the cars were all equipped with motors, or all the electric apparatus concentrated on one car."

Mr. Wallace stated that: "One of the practical difficulties in the way of placing motors on each axle of the car and on several cars of the train, and coupling them up so that they can all be used and under the control of one motorman, is that, so far as the author's investigations have gone, there is as yet no perfect and adequate controller in use in the United States which will provide for the proper manipulation of more than two motors," and his conclusions seemed to be that while a train system did not give that which was necessary, nothing had been presented to him in answer to all his inquiries and his painstaking research which gave him any promise of successful departure from his then existing method of operation.

There is small cause to wonder that the project for electrically equipping the Illinois Suburban was for the time abandoned.

At the time when Mr. Wallace's paper was presented, a committee, including himself and some other officers of the road, had been formed, with Mr. John Lundie as engineering secretary, and with a number of assistants was making some further investigations as to the possibilities of electric application. A report was made about the end of the year, and accompanying it was a proposal from me to guarantee a twenty-four and one-half mile schedule on the suburban service of the road instead of the eighteen and one-half which was then being accomplished by steam, and, if I am not mistaken, all further consideration of a locomotive pulling trailers was abandoned.

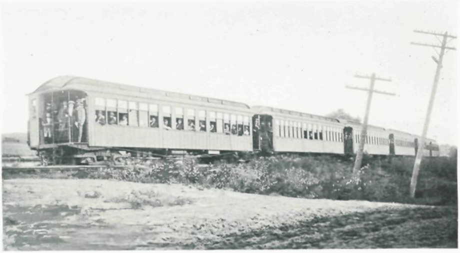
I think, as events have turned out, that with regard to the diametrically opposed views presented by Mr. Clarke and Mr. Knight, the former may well rest content with the position he assumed.

THE SPRAGUE MULTIPLE UNIT SYSTEM

Such was the generally unsatisfactory state of electric railway development for all else than ordinary street roads in the spring of 1897, and the conclusions which I have already given, together with apparent advantages which would accrue, pointed unerringly to the necessity of the third generic system of railway equipment and operation, that which I have termed the "*multiple unit system*," which is the most logical, and seems to me a finality in, railroad development. It may be briefly described as a semi-automatic system of control which permits of the aggregation of two or more transportation units, each equipped with sufficient power only tc fulfill the requirements of that unit, with means at two or more points on the unit for operating it through a secondary control, and a "train line" for allowing two or more of such units, grouped together without regard to end relation or sequence, to be simultaneously operated from any point in the aggregation.

For any given weight to be moved, whether it be in one or two cars, there is a certain capacity of motive equipment with which it is best to operate it under fixed conditions, and that is the motor equipment which should be put on that unit, not something either larger or smaller, and then when more capacity is required, to simply add another unit of like character.

A unit may be a single car or a pair of cars, and the number of motors used whatever desired. The logical equipment is two motors for each car, and when so equipped the importance of some of the practical results are emphasized.



FIRST MULTIPLE UNIT 6 CAR TRAIN—JULY. 1897

Among the advantages which such a general system when fully developed must possess, may be mentioned first:

SIMILARITY OF EQUIPMENT

This gives absolute flexibility of train operation.

It insures like characteristics for trains, whatever the length, and whatever the combination of cars.

The motor equipment is directly proportional to the number of car units.

There is a practically fixed relation between the weight on the drivers and the total load, whatever the length of train, and it is a matter of indifference to the motorman whether he is operating one car or any aggregation of car units in a train, for its characteristics are the same.

INDEPENDENCE AND FACILITY OF OPERATION

Each car being lighted, heated and braked independently, has independent movement in yards or car houses or on the tracks, wherever stored, and thus inspection, repairs and train combinations are facilitated.

The head and tail switching operations of locomotive practice are entirely abolished.

Trains in whole or in part can be reversed at any cross-over, thus reducing the dead mileage and intensifying the car movement to meet the conditions of passenger movement.

Cars can be added to or taken from a train in a third of the time that is possible with a locomotive system.

Where a system has main tracks with branches, car units for the different branches can be aggregated on the main line and then split at the junction, thus preserving the time intervals on the branches but doubling the distance intervals on the crowded sections.

The fullest use can be made of all sidings and tracks, wherever located, for storage, and in a large measure for inspection, which insures less dead mileage and useless returns, and effects concentration of car movement impossible where the cars must be stored in one place.

INCREASED SCHEDULES

Any required rate of acceleration or schedule speed up to the maximum becomes possible, thus giving the highest schedule with any given maximum, and the lowest maximum with any given schedule.

A partial equipment may be made by equipping alternate cars, and this schedule later increased by additions to the existing equipment without changing its character.

Local and express service can be operated with greater or less aggregation of motor equipments.

It has been suggested that with a locomotive system, when trains are reduced in length and the service on the road is diminished, the locomotive car can then increase the schedule, and that during the times of heavier traffic it still has capacity enough to pull a train. Such an argument is a reflection on the common sense of a railway manager, and such practice a parody on railway operation. The time above all when schedule speed, capacity and effective operation are required is when traffic is greatest and the road most liable to congestion. It is difficult to see how any engineer can seriously offer such an argument in support of locomotive practice, for it is directly contrary to the most vital requirements on a railroad.

If, as is vital in competitive service, a high schedule is necessary, and ignoring for the moment all questions about relative strains, weights, facility of making up and controlling trains, and the advantages of variable train lengths and intervals, when we come to six or seven-car train units a high schedule with short interval stations is impossible except with two heavy four motor locomotive cars or with every car equipped with a pair of motors. And from every point of view, the latter is preferable.

REDUCED STRAINS

This is of importance where elevated structures or bridges are used, especially when already possible strained.

It is apparent that the weight of cars, truck and motive equipment between columns is necessarily less than with any locomtive or locomotive car system.

All the longitudinal or shearing strains are greatly reduced.

The hammering on the rail joints, with the resulting shock to the structure and to the moving train, will be diminished because of the less weight per driver.

The thrust strains for any given rate of acceleration are equalized and distributed over a considerable length of structure, and become practically the reverse of the braking strains.

The strains on car bodies, platforms and couplers are reduced to a minimum.

INCREASED DENSITY

The safe time interval between trains for a given schedule and for any given length of train and station stop is dependent upon the maximum speed and the rates of acceleration and braking, and the greater these latter with any given schedule, that is, the lower the maximum speed and consequently the less the travel of the train after the brakes are applied, which distance varies roughly as the square of the speed at the time of applying the brakes, the shorter can be both the time and the distance interval between trains.

BROKEN MULTIPLE UNIT TRAIN—JULY, 1897

If there were an infinite rate of acceleration and braking, then there would practically be necessary, barring accidents, only that time limit between trains as is occupied by a train at and blanketing a station. In practice a motorman will approach a station with more confidence and under closer headway when his maximum speeds are low, and the braking distance which he travels short, and when he has confidence that the train ahead, once started, will promptly accelerate and increase speed while that of his train is rapidly diminishing.

It is apparent, of course, that the length of a train is only limited by the platform accommodation.

BETTER EQUIPMENT

From this standpoint better motor manufacture is insured. There are fixed limitations of wheel base, track gauge, wheel seat, diameter of axles and distances between axle and bolster, and hence there are practical limitations to the outside dimensions of motors. The smaller the capacity of the machine put into that space, the greater the margin for increase of dimensions of the essential working parts, such as bearings, gears and commutators, and the greater the freedom for inspection. Likewise, also, is there greater space for the application of any kind of brakes, electric or mechanical.

REDUCED NUMBER OF CARS

With any given maximum hourly mileage, the number of cars in service or on relay will vary inversely as the schedule. This advantage is further augmented by those already instanced, the concentration of car movements where most desired, and the storage of cars at the most convenient points, with consequent less dead mileage.

SIMPLICITY OF OPERATION

The operation of the multiple unit system becomes the simplest. Every motor car or pair being a transportation unit, and every aggregation of such being, so far as the motorman is concerned, simply an extension in the length of the unit without in any manner changing its character, the operation becomes almost automatic, a sort of second habit. Like hand and like train movement exists, whatever the combination and wherever the motorman is situated.

The making up of trains, so far as electrical features are concerned, is as simple as coupling up an air hose.

No main currents are carried from car to car, only hence less coal burned, for any given high schedule with like conditions of traffic than with a lower rate of acceleration because of the less amount thrown away in braking. The increase of power required because of low acceleration over high is anywhere from 25 per cent. to 50 per cent.

When it is realized that a system like the elevated railroad would use only one-sixth of the power actually used now if it made no stops the importance of this fact may be seen.

The question of coal economy is of less importance, however, than many other features of railroading, and, from a financial standpoint far less important than getting absolute freedom in determining train intervals and train lengths. In this connection it should be noted that altogether too little consideration is given to the question of car construction and car weights, and it seems to be forgotten by many engineers that useless tons of dead weight moved represents unnecesary investment in plant and a continuous charge against operating expenses, and it is about as sensible to ignore this question as it would be to add pig lead to a car having all of its weight on its drivers to increase its traction. If half the energy was spent in reducing useless tonnage moved as there is in bargain-

SOUTH SIDE TRAIN TESTED ON METROPOLITAN WEST SIDE ELEVATED RAILWAY NOVEMBER, 1897

small currents, through reversible jumpers, and the electrical combinations are effected automatically, however the trains are made up and whatever the end relation of the cars.

Protected by the automatic features, a child of ten years can handle full-sized trains on regular service with less trouble, so far as the electrical apparatus is concerned, and with less instruction than is required for the simplest form of air brake.

EASE OF INSPECTION

The train line and the main motor circuits being absolutely independent, and provision being made on any car for cutting out a set of motors, facility exists for an easy inspection, wherever the cars are located. Almost all the working parts of the motors can be inspected through the trap door in the bottom of the car, and since the cars have independent movement and can be rapidly run through an inspection shed over a pit, a little practice enables an inspector to make the most rapid survey of trucks, brake rigging, motors and everything else which is under a car.

ECONOMY

Transportation wages per car mile, the largest element of cost, are reduced because of the simplicity of operation, and because of the increased schedules. With the same efficiency there is less power per car mile expended, and ing on the cost per kilo-watt of apparatus, the cost per car mile and the ratio of operating expenses to receipts would be gratifyingly reduced.

SAFETY

The highest safety is essential. In the case of failure of brakes, or on slippery rails, the machines throughout the entire train can be safely reversed. The current input to the machines is automatically limited on each one to its safe capacity. In case an accident should happen to an operator and he lets go of his controlling handle, the entire power is instantly removed from the train, and in case the controlling apparatus on the leading car should become disabled the train can be operated from either end of any other car.

In fogs and on slippery rails a fixed schedule can be maintained more effectively because of the lower maximum speed, the less distance traveled in braking, the greater confidence in approaching a station, and the promptness of the leading train in getting away.

On account of the reserve capacity of the machines it is possible to make up time, and also clear a road, which is a matter of the gravest importance on a congested system.

The automatic cutting off of current will have an important bearing in a not distant future when a legislature is apt to, and should, prohibit the operation of a train with only one man in front unless there is some certain method of removing the driving power in case of accident to the operator. This is an instance of where an apparently small thing, possibly determining the employment of several hundred extra men, has a vital importance.

LEAST COST

The multiple unit system means lowest first cost as well as lowest cost of operation. This is contrary to first impression, but the explanation is simple in that the cost of the delivery of electrical energy to the car shoes per unit of constant use is eight to ten times the cost per unit of maximum capacity of car equipments, and by using the higher rate of acceleration rather than the lower for any given high schedule, the aggregate cost of the total equipment from power house to car equipments for any given hourly mileage is less, because, notwithstanding the increased cost of car equipment, the difference of economy creates a saving in that portion of the electrical equipment, that is generation and distribution, which costs so many times more per unit equipment than the units of car equipment, that the latter increase is more than made up by the saving in the former.

All this is readily proven, for I know of no problem presenting greater and more interesting possibilities of exact determination, so far as results are concerned, than that of electrical railway engineering; yet, on the other hand, I know of none in which there is a more reckless disregard of possibilties than in this very profession. In this, as well as in every other problem of kinetics or construction, and just as certainly as in the construction of a bridge, great increase of first cost, and cost of operation, may accrue from a disregard of the essential relations of all parts of the system, and on the other hand great savings may be achieved by a thorough knowledge of them.

Despite these facts, it is curious to note often times the inversion of the sound engineering with which the consideration of the electrical equipments of a road is often attended.

On any existing road whose traffic is known, the problem, put in the briefest form, *should* be:

Given the existing maximum car mileage and schedule, how best and most cheaply, both as to first cost and cost of operation, most quickly and with the least interference with service, and without increase of strains on elevated structures or bridges, can the existing mileage be maintained, how much can it be safely increased, what possible schedules can be made, and what will be the effect on the traffic and operating expenses of the road.

The fact that there is a most intimate connection between the generating, transmission and the motor parts of the equipment seems often to be lost sight of entirely, and yet even the ratio of gearing adopted on the car motor will affect the size of the power plant. The natural procedure would be to determine what results are desired, and then find the best method of getting them. Instead of that, often times a purely empirical decision is made as to portions of the equipment, such as the capacity of the central station and size of its units, and the results, so far as the movement of cars are concerned, left to take care of themselves. This procedure reminds me of the architect who, wishing to erect a sky scraper, would decide upon the foundation without regard to the weight of his building or the character of the soil beneath it, or the engineer who would build a bridge without knowing the load which will be put upon it.

There is, in fact, the most intimate possible relation, as should be perfectly evident, between the various parts of the equipment, and this relation is such that the costs of each part is seriously varied, with exactly the same schedule, grade and load conditions, by variations in the manner of making those schedules.

This is in no manner more effectively shown than in Mr. John Lundie's most interesting methods of detailing the essentials of first cost and cost of operation for various schedules under various rates of acceleration, all referred to a common factor, the percentage of weight on the drivers.

Such then are the practical advantages to be derived from a properly devised multiple unit equipment, but to be effective the details of the system had to be developed at great expense and much experience to a state of absolute reliability and reasonable simplicity.

It may be stated, now, that the essentials of the multiple unit system are not complicated, despite the remarkable variety of functions which they have. They may be stated briefly to be as follows:

1. The master controllers on the platforms at each end of a transportation unit. They are of the simplest and most reliable character.

2. The master controller and train line cables, which become parts of the permanent wiring of a car, and are just as reliable and as simple as that for the lighting system. These secondary controlling cables are absolutely independent of the main motor circuits, and carry very small currents.

3. The jumpers, which are removable sections of the train line, and connect the parts of the latter which are permanent to each car, just as air hose couplings connect up a brake line.

4. The main controller, which is composed of the following parts:

Certain relays and a throttle, developed in electric elevator service.

Pilot motor with automatic limits, something like that used in elevator controls, but of more robust make.

A rheostat cylinder, with or without motor grouping switches, the parts similar to those of hand control.

A reverser with like parts, but independently operated.

The braking system, whether using automatic air or electric, is something like the multiple unit electric system. There is a train line with means at each end of each transportation unit for simultaneously applying the brakes. When automatic air is used, there is a train and equalizing line, a compressor with an automatic governor, illuminated gauges and a simple form of engineer's valve at the ends of each car for each transportation unit.

THE MULTIPLE UNIT SYSTEM ON THE SOUTH SIDE ELEVATED RAILWAY OF CHICAGO

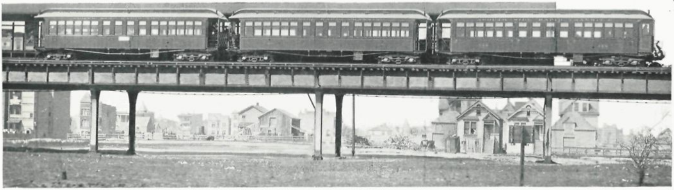
Like many other innovations, the opportunity to put the system which has just been described, and which promised so much, into operation was a long time coming. Many attempts had been made, with offers as already indicated to conduct experiments on a wholesale scale at my own expense, but with no satisfactory response, until in April, 1897, I was suddenly called in consultation on the South Side Elevated Road in Chicago.

This road had passed into the hands of a receiver, had been re-organized, and in the spring of 1897, had, under its new and energetic President, Mr. Leslie Carter, and a progressive Board of Directors, decided to adopt electricity, with Messrs. Sargent & Lundy as engineers.

The original plan submitted by the various manufacturing companies proposed the usual locomotive car with either two- or four-motor equipments, but many difficulties presented themselves in providing for the necessary power and weight to get the increased schedule speed demanded, as well as to meet other requirements. I at once saw the opportunity for a radical departure, and the opportunity to commercially put in operation a multiple unit system. The advantages of higher schedules, reduced weights, variable train lengths, more frequent trains, distributed motive equipment and increased economy being presented, with the plain statement that while the system was absolutely untried in railroad practice I was quite ready to back my recommendation by performance, found willing ears and the endorsement of the engineers, with the result that definite proposals resulted in a contract which in many ways was of similar character to that made for Richmond.

During the brief period of my transmission from the status of consulting engineer to that of contractor, a meeting in Chicago proved particularly interesting, for in the early part of April, 1897, scarcely more than two months after Mr. Wallace's paper before the Society of Civil Engineers, I had the pleasure of being present at a table when he made a statement about as follows:

"What I wish to do on way suburban traffic is to abolish the time table except at the dispatching terminus, and to send out frequent trains in succession whose length shall be one or a dozen cars according to the traffic requirements at the time of day, with orders to make the best time practicable on their round trip. In fact, I hope to see the time when I can run a train with a push button."



THREE CAR MULTIPLE UNIT TRAIN

Turning to him, I said: "That is precisely what I am in Chicago for at present." In fact, my report in favor of the multiple unit system had already been made to the South Side road, and a proposal for its equipment tendered.

It is suggestive also that it was very shortly after this that Mr. Cornell independently expressed himself very much as had Mr. T. C. Clarke.

However, despite the apparent soundness of the engineering and railway principles involved in the multiple unit system, the record of thousands of individually equipped cars all over the world, the many shortcomings of railway equipments depending upon locomotive practice, and the success and extent of the secondary control of single motors in elevator work, when the proposed plans for the equipment of the South Side road were announced the project met with the most radical and oftentimes unthinking objections from many electrical engineers. With the exception of the consulting engineers of the South Side road and a few former associates, whose confidence in my ability to carry out the contract was largely a personal one because of past relationship and acquaintance, and Mr. W. J. Clark, the then manager of the railway department of the General Electric Company, for whose personal support I am much indebted, I recall few instances of professional support.

I had, however, been through too many experiences of the kind to be discouraged as to the outcome, and I received cordial support from the various sub-contractors, who willingly accepted orders for material under conditions somewhat out of the usual, and it is to their active co-operation in this respect that much in the way of the possibilities of the multiple unit development on the South Side road is due.

The criticism which was poured in on the South Side officials, however, was not without result, for realizing the gravity of the proposed departure in practice, the contract requirements were made of the most rigid character, and the conditions under which the equipment was to be installed were most exacting.

In fact, considering the importance of the contract, all the negotiations for its conclusion were somewhat out of the usual. With the exception of a short period of consultation in Chicago, most of the engineering correspondence was carried on by telegraphic correspondence, and the contract in its final form was signed without my seeing it by my assistant, Mr. McKay, while I was out of the country, the contract itself having been prepared by the officials, advisers and engineers of the South Side road, with what care in protecting their own interest one can well imagine.

The physical conditions were as follows:

The existing road is a double track structure of the usual elevated type, extending from Congress street to Stony Island avenue, a distance of about eight miles. Plans were already made to connect it with the new "Loop" in the heart of Chicago, on which the trains of the Metropolitan and Lake Street roads were already operating, and which was to receive also the trains of the projected Northwestern Elevated, with the prospect of grave congestion and the absolute necessity of freedom from serious blockades which would stall the entire elevated system of the city.

The road is paralleled by cable and electric street systems, by the Chicago & Rock Island road, and by the superb suburban service of the Illinois Central.

The existing equipment consisted of forty-six twenty-eight ton Baldwin compound locomotives, and 180 standard forty-three foot fifteen-ton cars equipped with Pintsch gas, steam heat and automatic air brakes.

The schedule speed on the main lines was fourteen to fourteen and one-half miles an hour; trains were operated at intervals of one and one-half minutes to half an hour, and in lengths of from two or five cars; the service including the Loop would, in the cold weather, require 145 to 150 cars, and ten or fifteen cars would ordinarily be under normal repairs.

It was necessary to take this equipment in its then condition, remove ten or fifteen cars at a time from the structure, partially equip them, return them to the road to allow them to be retained in steam service, to again withdraw them, complete the equipment, and put them into electrical operation when the power house was ready, jointly with steam trains, without crippling the service.

The contract required the supplying and installation on 120 cars of lights, heaters, motors and trucks, as well as the developing *de novo* of an entire new system of control, involving not only the actual construction of the controlling mechanisms, but the train system connected with it, such as couplers, jumpers, automatics, etc., the installation of a braking system, and the providing of both ends of the cars with vestibules or cabs. Nine-tenths of the apparatus was not of my own manufacture—even the motors were not of a commercial size.

The following were among the required conditions of operation:

The simultaneous control of two or more independently equipped motor cars, to start, accelerate, operate at any speed up to the maximum, slow down, and apply automatic brakes, all with practically uniform effect in each and every motor car.

The automatic reversal and braking of the machines and cars in case of failure of current, parting of train, or running on to a dead section.

With a normal potential of 500 volts, a single motor car, or any number connected together in a train, to be able to maintain a schedule speed between existing termini of fifteen (15) miles per hour, with average stops not exceeding ten (10) seconds, for existing station distribution, and to be able to ascend a 2 per cent. grade at more than schedule speed.

The system of control to be such that any number of cars so equipped could be coupled together indiscriminately without regard to their sequence, and when so coupled, by identically the same movement to be controlled from any selected point at either end of any car, and the rate of acceleration, traction co-efficients, speed and braking conditions which characterize a single car to be duplicated in a train unit no matter what the number of cars.

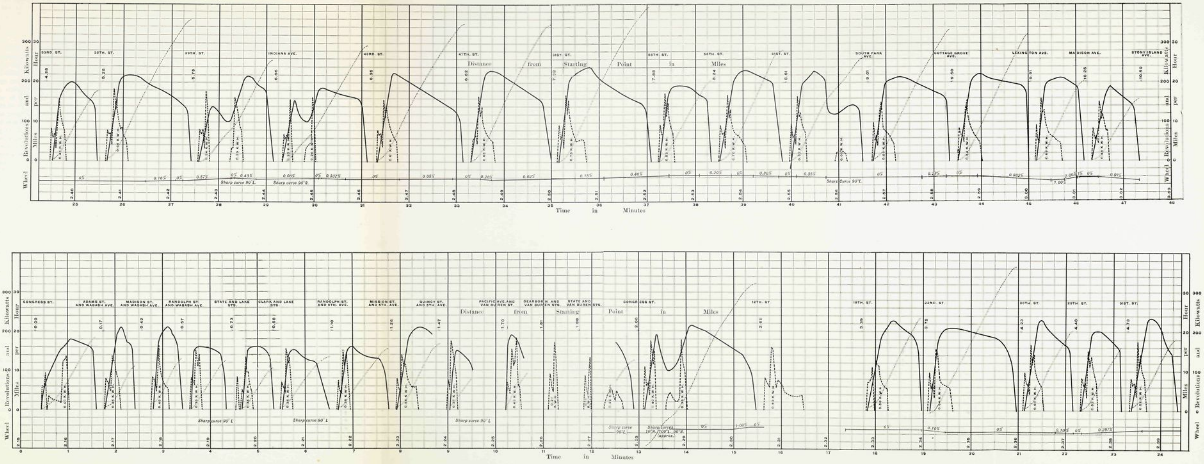
The automatic braking devices and electrically operated power brakes to furnish a perfect substitute for the air brake in use, in efficiency, reliability, and automatic action.

The contractor was to begin work on the equipment on 120 cars immediately upon signing of the contract, and to have six cars completely equipped, ready for operation and test concluded on or before July 15, 1897, on a standard track not less than one mile in length, to be supplied by him at his own expense; the test and the manner of its making, as well as its extent, to be prescribed by the officers and engineers of the road, and to be to their entire satisfaction. Should such test be unsatisfactory to any of these officials, or not be concluded by the date set, then the right remained with the Railway Company to cancel the contract. Should the test prove satisfactory, the cars were to be delivered wherever required for further tests, the remaining 114 equipments to be progressed to completion by specified dates, and as soon as the South Side power house and road were ready for electric operation, another test was to be made of twenty or more equipments under the actual service conditions of the road, which test was to extend over a period of at least ten

FROM STREET RAILWAY JOURNAL, DECEMBER, 1898

SOUTH SIDE ELEVATED RAILWAY, CHICAGO

CURVES OF ACCELERATION, SPEED, DISTANCE AND POWER CONSUMPTION



SPRAGUE MULTIPLE UNIT SYSTEM

TESTS MADE SEPT. 3, 1898, ON CAR No. 166—COMPLETE SINGLE (OUT BOUND) TRIP

CAR EQUIPPED WITH 2 G. E. 57 MOTORS

days, and be made in such manner as required by and to the satisfaction of the president and engineers of the company.

In the event of these equipments proving unsatisfactory to any one of them, the company still had the right to cancel the contract, and to require a waiver of all claims against it. No acceptance of any part of the equipment could be required by the contractor until after these specified tests.

In addition, a $100,000 penal bond, in form drawn by the Railroad Company, for the carrying out of the contract had to be filed.

All these conditions were accepted, and while the installation on the road, from the contractors' standpoint, bears a striking similarity to the immediate commercial outcome of the Richmond equipment, the results will probably be equally historical.

The progress of the experimental equipment was erratic, and many of the conditions unknown, for before the signing of the final contract I had gone abroad for the purpose of getting the elevator equipment for the Central London Railway, an engineering proposition of no mean magnitude, but which was finally awarded under much the same conditions and risks. I did not return until after the middle of June, so that most of my instructions concerning the trial equipment were given by cable and the actual work of construction and preparation was done within thirty days.

However, on the 16th of July, 1897, two cars were put into operation on a private track, at Schenectady, in the yards of the General Electric Company, which company, as well as a number of other sub-contractors, had accepted conditional orders from me for the various portions of the equipment which they could supply, and had, as a condition of procuring the order, offered the use of their tracks for experimental purposes.

On the 26th of July, the fiftieth anniversary of the late Professor Moses G. Farmer's test of an electric car at Dover, N. H., a train of six cars, operated by my ten-year son, Frank D'Esmonde Sprague, was put into operation, and tests of the equipment in the presence of the officers and engineers of the South Side road were continued for several days. All the apparatus was of course temporary.

On November 17th, a train of five cars was put into operation on the Loop and over the track of the Metropolitan Elevated Railroad, and continued for a number of weeks, operating sufficiently satisfactorily to warrant the completion of the contract which was then in active prosecution.

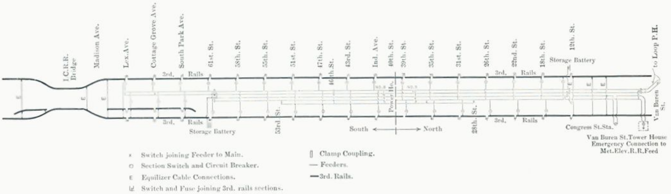


DIAGRAM OF DISTRIBUTION SYSTEM—SOUTH SIDE ELEVATED RAILWAY

The first car was run on the South Side Road April 15th; on April 20th, twenty cars were put into initial operation, seventeen of which came off by night because of defective rheostats, but by July 27th, locomotives had been entirely abandoned.

Subsequently thirty "train line" cars, for insertion into trains during periods of heaviest operation or on special occasions, were added, and since then thirty more cars have been fully equipped.

This review would not be complete without here acknowledging my many obligations to the officers and engineers of the South Side road for their confidence and patience, as well as the hearty co-operation and support of my own business and technical associates in the Sprague Company, during many trying and critical periods.

A description of the actual equipment of the road may be made under the heads of power house, track system, storage battery, and car equipment and control, with some notes as to the practical operation and the results obtained.

POWER HOUSE

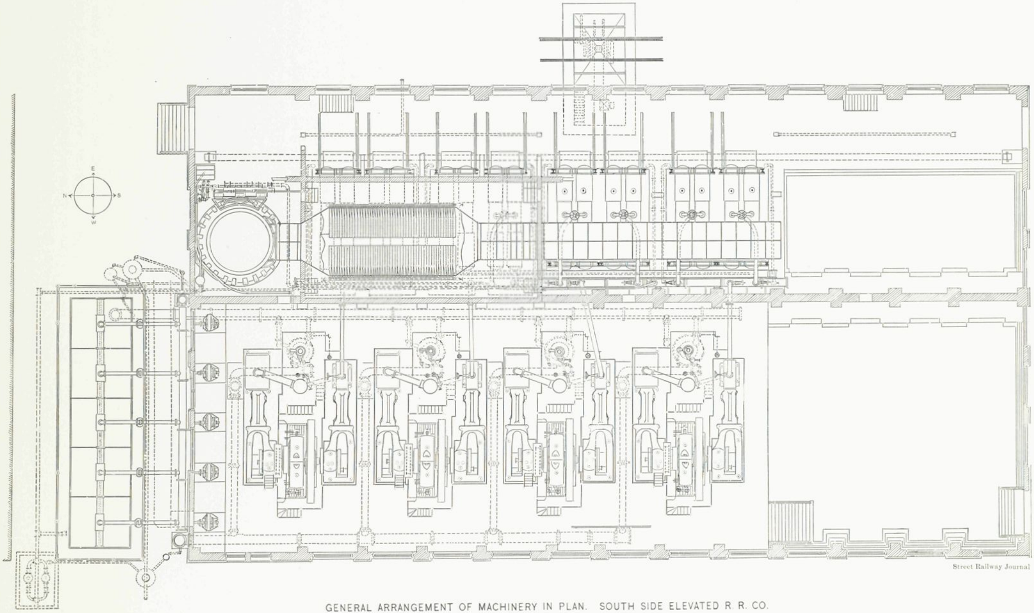
The power house was built after plans by Messrs. Sargent & Lundy, and embodies several features which successfully obviate the disadvantage of a site removed from water supply sufficient for condensation, but which was chosen because it was near the center of distribution for the railroad system.

The building is of brick and iron, unpretentious in design, and the engine and boiler rooms are separated by a brick wall dividing the building longitudinally.

The boiler installation at first installed consists of four batteries of Babcock and Wilcox water tube boilers, rated at 400 H. P. each, equipped with chain grate stokers filled from overhead coal bunkers of 1,000 tons capacity.

The chain grates are engine driven, and have speeds adjustable for ranges up to four inches per minute. Vertical shutters at the feed hopper on the boilers regulate the depth of fire on the grates. The installation operates practically smokeless, except in starting fires. Ashes drop from the grates into sub-chambers, and are drawn off into an electrically driven coal and ash conveyor, which receives and dumps automatically when set as desired and started.

Furnace gases on leaving the boilers pass through a Green fuel economizer with dampers at entrance and exit. This economizer effects 10 per cent. fuel saving.



GENERAL ARRANGEMENT OF MACHINERY IN PLAN. SOUTH SIDE ELEVATED R. R. CO.

The engine room is traversed longitudinally by an electric crane of thirty tons capacity.

It contains four cross-compound condensing Allis-Corliss engines each rated at 1,200 H. P., at eighty r. p. m. with maximum capacity of 2,000 H. P. each. They are of special heavy railway type, with twenty-four foot fly-wheels each weighing fifty tons.

Steam is furnished at 150 lbs. gauge pressure and exhausted in a condenser vacuum equivalent to a 24-inch column. The condensing apparatus is of the Allis vertical type, and is independent of the engine.

Adjacent to the main building is a rectangular Barnard cooling tower sheathed with 1/4″ steel plate and divided internally into five vertical sections, each provided at the bottom with two ten-foot fans carried on the shaft of an eighteen H. P. motor. The fan speeds may be varied by three different motor combinations. The condensing water is delivered to a distributing header 30 feet above ground level. Thence five mains distribute it into drip pipes in the several sections, where the water trickles downward over wire mats continuously fanned by the cool air blast from below. The final temperature of the water is about 85° F.

The electric generators are four 800 K. W. twelve pole Westinghouse compound wound dynamos with large overload capacity. The field pieces are vertically split and can be slid at right angles to the shaft, giving access to the armatures which are mounted directly upon the engine shafts.

The main switch-board is made up on the panel plan and so fitted with instruments as to record separately all sub-divisions of the power generated.

The station shows great operating economy in practice.

A complete power house shift including chief engineer and clerk, including nine men, five of whom rate only as helpers and oilers. Hence the labor cost is very small.

The power house records show that the total power house cost per kilo watt hour delivered to the switchboard is less than one-half a cent.

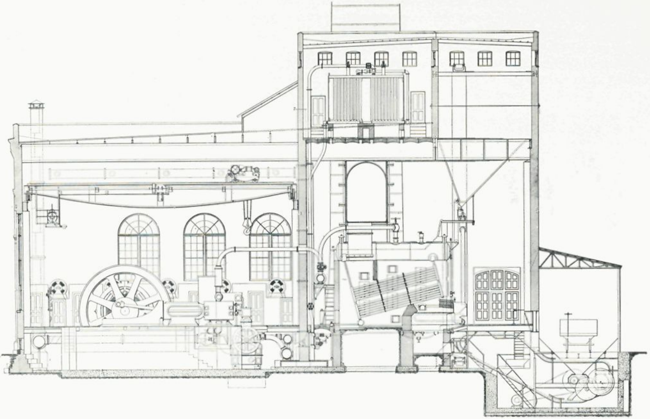
DISTRIBUTION

The system of distribution is a modified plan of what is popularly known as the "Third Rail" system.

Extending from end to end of the line, on the inner side of each track and along all switches and cross-overs is an ordinary forty pound T-rail, in sixty foot lengths, supported on insulators at short intervals, and with its surface about 4 inches above the working rail and a few inches from it. This rail is bonded at every joint with double horse shoe bonds to provide continuity of circuit. It is known as the "power rail," it forming one terminal of the electrical system, and is the rail with which flexibly mounted shoes carried on the car trucks make contact.

This rail is divided into sections of varied length, which sections, instead of being left open as has hitherto been the practice, are joined together by switches or fuse blocks so as to make the rail electrically continuous under normal conditions, but with provision for cutting out a section automatically or at will in case of short circuiting.

Extending each way from the power house are five feeders carried on insulators on the center of the structure under a housing, the majority of these feeders being connected to the power rail sections by sub-feeders through circuit breakers at various points. One feeder goes to a connection between the South Side System and the "Loop" for emergency, and two of the feeders are used in connection with storage batteries which are placed each at ap-



SECTION OF POWER STATION—SOUTH SIDE ELEVATED RAILWAY COMPANY proximately half the distance each way from the power house to the ends of the line.

The return circuit is made through the tracks, which weigh ninety pounds to the yard, are bonded at each joint, and cross bonded every 120 feet.

There is also a permanent connection between the power rail of the South Side System and the "Loop" through a fixed resistance, and cars and trains in passing from one system to the other at times receive current from both stations, and they are also directly connected together at the time of transit through the shoes on cars passing over the gap.

STORAGE BATTERIES

The introduction of the storage battery on elevated work, which is a step in the progress towards high tension long distance transmission with local sub-stations for railway operation over considerable distances, was made on the South Side for the first time in elevated railroad practice. The high schedule required, the number of trains in operation, and the consequent heavy demands for current due to quick acceleration and aggregated loads produced a somewhat more marked variation in the central power plant than would occur with less severe transportation demands. The batteries therefore act as equalizers for the central station, reduce the drop of potential on the line, add greater reliability to the power supply, and in some measure carry a proportion of the peak load which is characteristic of elevated practice, where the great bulk of traffic is carried in the morning and in the evening in limited hours.

Each battery consists of 248 cells, "chloride" type, made by the Electric Storage Battery Co., of Philadelphia. Each cell has twenty-six pairs of plates, and they are carried in lead lined tanks built for twice that number so that the battery capacity can be easily doubled.

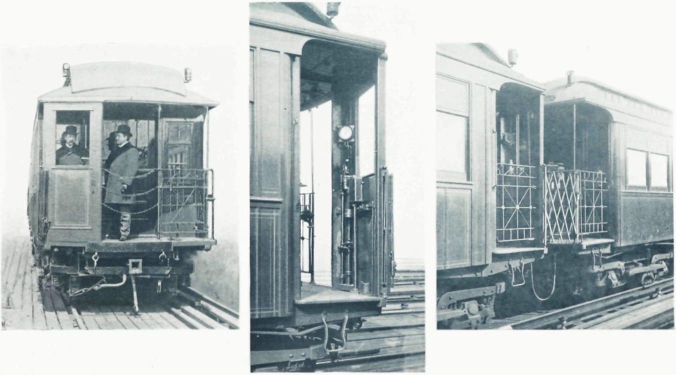
Each battery has a capacity of 535 kilo-watt hours at the hour-discharge rating, and can easily discharge fully 60 per cent. above this with safety. The nominal charging rate is about one-quarter that of the hourly discharge, but of course it can be increased when necessary.

Some addition to the battery has recently been made because of the increased service demands.

The batteries are placed in multiple with the line without any booster. Their operation is entirely automatic, each one acting both as a reservoir for energy and a regulator of the voltage. Of course, one practical effect is to increase the capacity of the supply system, and in operation the present battery takes the place of one unit at the station.

CAR EQUIPMENT AND CONTROL

We come now to the car equipment and system of control—the multiple unit—which is the distinctively characteristic feature of the whole installation.



DETAILS OF PLATFORM, CAB AND MASTER CONTROLLING MECHANISM—SPRAGUE MULTIPLE UNIT TRAIN—1898

It has been already pointed out that the multiple unit system is an aggregation of transportation units of variable size, each equipped with the power required to operate that unit at a given schedule and under determined conditions, with means for controlling the aggregation from two or more points. This does not necessarily mean that every *car* is equipped—that depends upon the schedule and the requirements of acceleration—for the method is equally applicable whatever the number of cars that are equipped with motors or the number of motorless, or "train-line" cars which are mixed in with them. For example: A train can be made up of pairs, each of which forms a transportation unit consisting of one motor and one motorless car, so that the train units can be made up of two, four or six cars that is, one, two or three couples, thus averaging one motor per car in use.

Three and five car trains can be made up, the third and fifth being a motor car or a train line car.

In any case, two-motor equipments can be put on one-half of the cars, and the balance equipped with a train line so as to get one schedule, and when it is desired to increase the schedule motors and a controller can be added to the partially equipped cars.

Of course, the finality of the system on roads with frequents stops, to get the maximum schedule speed, is a motor on each axle, but in a large number of cases, and with pivot truck cars, commercial demands are such that two motors per car is sufficient, and on some service ,two motor on alternate cars only.

The equipment of the South Side road has been made on a mixed plan, 120 cars first being each individually equipped with two motors, then thirty cars with a "train line," but without motors, and finally thirty additional cars completely equipped.

The position and arrangement of the South Side yards, and the running of trains into a Y at one end and around a loop, at the other produces every possible aggregation of cars. Hence for the equipment, in order to avoid head and tail switching, and to permit of this variable aggregation, there was one vital condition, which was that, no matter how trains were made up, like hand movement at the end of any car must at all times mean like track movement relative to the operator, and the system of connections from one car to another must automatically provide for such a result.

This variation of car aggegation, and the further condition that no seat room should be taken up by the motorman, made it necessary to provide each car with a movable cab on the platform such that it could be left open for the free use of the ordinary entrance gate when in the body of the train, and yet be readily closed and afford protection to the motorman when at the leading end, at the same time allowing free passage from one car to another. On each car, therefore, at the right hand diagonal corners the iron work has been removed, and a three part cab constructed, the outer end being a fixture with a drop window, and carrying in the angle formed by the platform the initial controlling mechanism, being the master controller for the electrical system, and the engineer's valves for the air brakes. On each side is a door, each hinged in opposite direction, and folding back one over the other against the header of the car, leaving when in this condition the platform clear, and the ordinary gate in operation.

When used by the motorman, one or both doors are closed, the iron gate swung in place, and a small protecting cab is the result.

Under one end of the car, in place of the ordinary truck, is a motor truck carrying two fifty H. P. (hour rating) standard railway motors of capacity and gearing such as to safely allow the motors to work up to the skidding point of the wheels with 60 per cent. of the weight of the car equipment and load upon them.

The motors are of the General Electric manufacture, and of the usual Sprague suspension.

In the hood of each car is a controller for the motors enclosed behind a trap door which can be lowered for ready inspection. The controller is of the multiple-series type, is driven by a small pilot motor, and provision is made for at will or automatically producing a step by step, or interrupted, or periodic forward movement of the controller, and a continuous or interrupted return movement of it to the off position through various automatics connected with the pilot motor and the initial control circuits.

In addition to the current varying controller, there is a main reverser, likewise operated by the same agencies as the pilot motor, for determining the direction of the current delivered to the motors, and for instantly opening the circuit of the motors in case of emergency.

Inside of each cab is a small master controller or operator's switch mounted on a standard, and fastened to the wood work of the cab. Through this master controller the pilot apparatus of the current varying controller and the reversers are governed. It is provided with a movable handle, operating a spring retracted spindle, which through various degrees of movement makes contact with the reverser circuit and with three determinate positions, coast, series, and multiple. Momentary contacts on these various points give any desired intermediate position of the main controller, which has a stepped movement. In order to maintain the controller at any point, or to keep the governing circuits or train lines energized, the handle of the master controller must be held in position. If the handle is released, whether from accident or design, the spindle instantly returns to coast position, and the controller automatically returns to the off position and cuts off the current, or if the master controller is allowed to go to the center position, the reverser is instantly opened, and the controller then comes to open circuit also automatically.

The arrangement of circuits is such that by the use of a relay and throttle and the proper interconnection between the controlling circuits the operator is at liberty to do about as he pleases with the master controller, and can rely upon the main controller operating satisfactorily.

For example: He can go to the series or to the multiple position, or, from the last, reverse movement instantly, and the controller instead of responding instantly operates progressively, the pilot being limited in its movements by increment of the main current to or above any definite amount.

The throttle is set just short of the skidding point of the wheels on a normal track, allowing 15 per cent. adhesion, and absolutely limits the current input to that which is required by the determined rate of acceleration. Any rate less than this can also be effected by proper handling of the motor controller, so that any movements, no matter how refined, are perfectly possible.

This throttle is in the circuit of one motor only, so that it is equally effective whether in the series or multiple position.

Although there is a master controller on each platform, their construction is such that interference with them is difficult, and has never been known to occur. Of course, they could be made removable.

So far, the system described is that of a secondary electric control of a single controller, but by paralleling the relay and other circuits it is evident that the two or more equipments on a single car can be operated, and also that if these equipments are put on different cars they can likewise be operated provided means exist for properly connecting the prime controlling circuits, and insuring practical synchronism of the different controls and equal work on the different motors. Where the equipments, however, are on different cars, it then becomes necessary to have a "train line" and couplers, so that a governing circuit which can be energized at various points is made up of a train line individual to each car and couplers of some kind between them.

This train line is necessarily an independent line, not being a part of the main motor circuits on any car. It can be energized, of course, from any electrical source, but for convenience the main course of supply is the one used.

This train line consists of five wires, perfectly insulated, made into a common cable permanently located in the car, and terminating at each platform in one or more couplers, in this particular case in a pair of couplers, one under each corner of the platform, these couplers being shrouded so as to prevent dirt or rain entering them.

When trains are made up the train lines are connected by a reversible jumper having corresponding wires, and the system is so disposed and connected that no matter from which corner the connections are made, or how the cars are reversed or altered in sequence, the circuits are automatically established so that like track movement is always assured with like hand movement of the master controllers.

The section of train line in each car is not a part of the normal controlling circuit individual to the control equipment, but is connected with it with switches which enables a severance of the two systems, that is the local

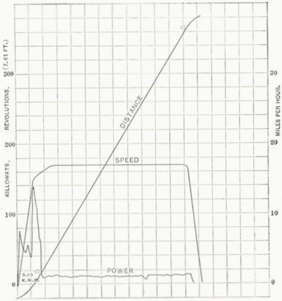


FIG. 1.—ACCELERATION AND SERIES OPERATION CURVE

car system and the train line, so that no matter how trains may be made up it is always possible to disconnect the controlling mechanism of any train for any purpose whatever.

The practical result of the system is that every aggregation of cars, whether one or more, has identically the same characteristics in the matter of load, capacity, motor equipment, rate of acceleration, etc., as are possible with a single car, and every combination is made without the slightest thought being given to pairing of electrical circuits.

Each car is equipped with an automatic air brake system, supplied by Christensen air compressors, with a reserve tank, and an equalizing pipe running from car to car, the compressors being started and stopped automatically through an air governed switch by fall and rise of air pressure.

On each platform, alongside of the master controller, is a small engineer's valve, so that from any selected cab the air brakes can be operated with equal facility.

A balance wire runs throughout the train, and is included in the same coupling as connects up the electrical train line, so that when an air governor on any car closes circuit, all compressors start and continue in operation until the last governor throws out. This is to effect equal work on the various compressors, and to maintain absolute certainty of air supply at all times.

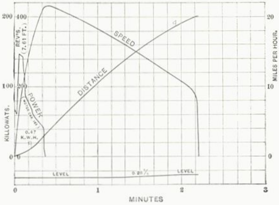


FIG. 2.—ACCELERATION AND COASTING CURVE

If a train should part, three systems of automatics come into play. The reversers go to open circuits, the controllers to the off position, and the air brakes also automatically operate.

If the main circuit fails, all reversers open instantly, and the controllers must come to the off position, which they will do automatically as soon as current is restored, before current can again be put in the main motors.

So, too, if there is an instant reversal of the master controller. The reversers first open circuit, the controller returns to the off or any determined position, then start again, and are instantly arrested on the first contact. Provision is made so that it is impossible to run backward at more than one-half speed from any platform when operating from that platform.

The cars are of course electrically lighted, and are also provided with electric heaters.

For several weeks, on account of lack of equipment, the motors on the equipped cars in the morning and evening hours were subjected to a regular increase of load of

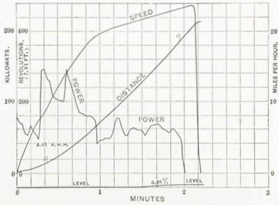


FIG. 3.—SLOW ACCELERATION WITH NO COASTING

about one-third and at times every motor car has been in operation. The economy of quick acceleration for high schedules has been thoroughly demonstrated, and Fig. 2 gives a section of a run which is typical of operation when coasting freely. On this test, with car making, fifteen mile schedule, and under the conditions of grade and station intervals on the South Side road, the energy used at the car was about seventy-three watt hours per ton mile.

The accompanying inset between pages 16 and 17 shows an actual run with existing station distances.

Fig. 1 gives an illustration of what is sometimes preferable practice, particularly in fogs, a quick acceleration to a somewhat lower maximum speed, and then operating motors in series to maintain a constant or slowly diminishing speed to the point of braking.

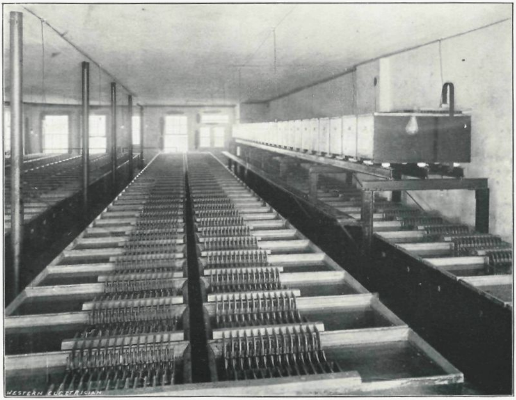
These form an interesting comparison with the curve shown in Fig. 3, that of a motor car pulling three trailers, which is typical of locomotive car practice on frequent service. It will be noted that the acceleration continues to the point of braking, the most uneconomical method of operation.

were greatest. At times, 65 per cent. of the one track on the Loop was covered by cars from three different lines.

On this particular day, when the car mileage was increased about 80 per cent., and with very heavy loads, the central station had six 400 H. P. (standard rating) boilers only in use, with but two men in the fire room, and there was no straining of engines, dynamos or batteries.

As an example of extraordinary duty, the operation during the recent holidays may be cited. During a good portion of the time the central station is reported by the consulting engineers as operating as follows:

Fifty per cent. overload for six hours; full load for seventeen hours, and 74 per cent. load factor for twenty-four hours.



STORAGE BATTERIES SOUTH SIDE ELEVATED RAILWAY COMPANY

A very large number of records have been taken by Mr. Lundie, these running into the hundreds, under all possible conditions of acceleration and all sorts of motor and trail car combinations, for determining the best methods of operation, the highest degree of economy under various loads, and for ascertaining track, car and gear resistances, resulting in a very satisfactory equation with speed and weight as factors. These are conclusive of the benefits of this method of operation, independent of the influence on passenger traffic of high schedule speeds and short time intervals.

The system was put to the hardest test on October 19th, Jubilee Day, and although operating with only 148 cars on nearly twenty miles of total trackage, 240 cars per hour were sent into and out of the Loop at Congress street hour after hour without a hitch. This was done by reversing trains at cross-overs at three or four different points, thus intensifying the car movement where traffic demands

Out of 120 motor equipments designed for individual operation, 119 were in daily operation morning and night, with twenty-eight or twenty-nine trailers, thus overloading the motors one-third, and often these trains, coming out of the Loop from two to five minutes late, have made up time before reaching the end of the run, but naturally of course at a loss of efficiency.

The average duty of this equipment is higher than that of any other elevated railroad in the world. Cars have frequently made as high as 290 miles a day for days in succession, and the average maximum of cars in operation for long periods ran to nearly 100 per cent.

Financial, not alone technical results are a measure of success, and a comparison is therefore in order.

The months of November and December, 1897 and 1898, are the first strictly comparative months.

The road then included "Loop" operation, 19.44 miles of track, in 1897 was operated entirely by steam, and in

1898 entirely by the Sprague Multiple Unit Electric System.

In addition to all "Loop" expenses there is a rental charge equal to 10 per cent. of the gross passenger receipts of the road. This should be considered really as an interest charge, not as an operative expense.

For these two months with an average of 489,979 car miles on the main line, the comparative table following shows:

(a) Ratio of expenses to earnings, *including* "Loop" rental, taxes and licenses;

(b) Ratio of expenses to earnings, *excluding* "Loop" rental, but including taxes and licenses;

(c) Net earnings.

	(a)	(b)	(c)
November '97, Steam,	87.3	77.7	$10,603.80
November '98, *Electric*,	57.3	47.7	39,448.56
December '97, Steam,	83.6	73.8	14,691,69
December '98, *Electric*,	55.0	45.4	45,355.68

The succeeding months show increasing traffic and equally favorable results.

The operating expenses per car mile during November, 1898, on the main line, including and properly apportioning to it everything except licenses, taxes and rental, were less than seven and one-half cents on an average and maintained schedule of fifteen miles an hour, with stations 2,080 feet apart.

So much for the actual results accomplished on the South Side road. The question naturally arises: Have there not been difficulties, and if so, of what character?

Of course there have been, and I should have been surprised, and almost sorry, if it had been otherwise, because it is only through the difficulties incident to the earlier operation of a system of this character that the essentials are fully determined, and apparatus developed to a state of perfection.

It is curious, however, that there have been more troubles with what is classed as "standard apparatus" than with that individual to the multiple unit control. These troubles were, first, with the rheostats, which were of new construction, and later, poor brush terminals, cracked gear cases, and with the earlier type of air governors.

With the specific multiple unit apparatus the principal troubles were with poorly and hastily wound relay coils, too light and unsubstantial construcion of auxiliary contracts, and improper jumper construction, causing an occasional opening of the controlling circuits.

Taken all in all, however, the president and superintendent of the road state that there were less troubles than when starting with their compound locomotives, and on the whole the success of the road has been unparalleled in electric railway history where so radical a departure has been taken.

ESSENTIAL FEATURES OF ELEVATED AND SUBURBAN RAILWAY EQUIPMENT

Coming to New York conditions I may say that, based upon the Chicago performance, and allowing for difference of coal cost, the Manhattan road, now operating at twelve and one-half miles actual schedule during time of maximum load, and making about 43,000,000 miles annually, can be operated at over a sixteen-mile schedule at not exceeding nine cents, instead of 11.9, and on the existing mileage this would mean a saving, excluding interest on investment of about $1,250,000 per annum, or allowing interest on investment of about $750,000, to say nothing of any other gains. A seventeen-mile schedule can actually be made with two motor equipments.

In closing, perhaps I may venture an opinion as to the general features which should characterize a suburban passenger railway equipment. I think it may be safely stated that the first is the use of the continuous current in the motor equipment in spite of the claims which have been made and the results accomplished with alternating current motors, at least so far as we can judge by any present developments.

The problem then is whence shall be derived this continuous currents, and that depends upon distances. For moderate distances, continuous current generators supplying current directly to the line, with or without the addition of storage batteries, is preferable. When the extent of the line becomes at all serious, then it must be considered as made up of a number of shorter sections joined together, each of which derives its principal source of supply from a local station, which station can be driven directly by water or steam power, or by an alternating current from a distant station, using a motor-dynamo combined in a single type of machine, the rotary converter, or joined in the form of a directly coupled set, the dynamo end being for continuous current and the driver a synchronous or induction type of motor.

Generally the sub-station should be supplemented by a storage battery, to take care of fluctuations in the load, to even up the duty on the sub-station and as far as possible at the central station, and to take care of some portion of the peak load caused by abnormal variations in the aggregate service at different times of the day.

Of course, with the storage battery comes the necessity of a means of some kind of automatic regulation; there are various methods, but I will not enter into them here.

Looking forward, however, to a perfectly assured future of a heavy service over considerable distances, I may state that the general equipment of such a road should generally involve the following essentials:

High potential alternating current transmission from one or two well placed central stations, with or without static transformers.

Motor-dynamo sets, or rotary converters at a number of conveniently placed sub-stations, to convert high pressure currents into continuous currents of about 600 volts pressure.

Storage batteries of quick charge and discharge capacity, generally at the same sub-stations as the motor converters, to equalize their duty and to prevent sharp variations in the general plant as well as the sub-station.

A system of feeders and main conductors.

A power rail or trolley wire supplying continuous current, but ordinarily without any switching of currents.

Individual transportation units with a multiple unit control, so that combination of cars without regard to sequence or end relation can be made up at any portion of the line independently, and controlled from any selected point.

A DISCUSSION BY MEMBERS OF AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

MR. BLOOD: I would like to ask the maximum acceleration you get there in either pounds per ton or feet per second

MR. SPRAGUE: I cannot answer definitely as to present practice, not having been there for months. I have seen a number of records showing an average mile-second rate up to time of cut-off, and for the first seven-tenths of speed, before working on the motor curve, a one and a half mile-second rate.

MR. BLOOD: Do you get as high as 100 pounds?

MR. SPRAGUE: Yes, we do that quite easily.

MR. BLOOD: I know you can, but I was wondering if you did.

MR. SPRAGUE: Yes, I think so, but I haven't the records with me. I think very likely there are some gentlemen in the room who have been making tests on the road who can answer that question better than I can. We have gone up to the slipping point of the wheels, which would be 300 pounds for each ton on the drivers with normal condition of track. We do not force the machines to quite that extent. Being a two-motor equipment with double trucks, we average 61 per cent. on the drivers, and that does not vary with the load more than about 3 per cent. either way. Fifteen per cent. adhesion gives 300 pounds to the ton if everything was on the drivers. We can certainly work to over one hundred and fifty pounds actual pull.

MR. BLOOD: I notice some of the best tests in braking give a maximum about 200 pounds.

MR. SPRAGUE: Of course, in braking you have every wheel in operation, and also all your weight. If you should work up to the slipping point, we would have 180 pounds, provided the track is in good condition. We do not work quite so high, for that would leave no margin.

A MEMBER: What would happen if the pilot motor jambed or burnt out so that the controller would not respond?

MR. SPRAGUE: That could not well happen on all the cars at once. There is no possible excuse for small motors being made so that they are not reliable. This particular controller will handle two fifty H. P. motors, each of which is guaranteed to work up to 100 H. P. It is not a very large piece of apparatus—in fact, about the size of an ordinary street car controller.

To operate one of these requires an eighth of a horse power pilot. This pilot runs cold, because it only operates spasmodically. It has only a fraction of the duty a fan motor of the same rated capacity has.

But let us assume the possible condition of a jambed controller. Nothing disastrous will happen. If we wish to open the circuit, we can do it instantly on the reverser without regard to the main controller, and, having once opened, it is impossible for that particular reverser to come back until its controller has been returned to any determinate position it is set for. The reverser circuit passes through split paths. The initial path is through a contact carried on the main controller, which, when the controller has advanced one step, is entirely cut out, but a supplemental circuit dependent on the current in the reverser circuit itself has meanwhile been made, which maintains that circuit although the original path is open. If this supplemental contact for any reason opens, there is no method of again making the main circuit on that car until that main controller comes to any required position, generally the coast or first contact position. Of course, if there are three or four cars in a train, one equipment can be entirely cut out, and the schedule speed made by forcing the balance of the motors. It is a matter to which we pay little attention in practice. This possibility was one of the first things which occurred to us, but it was met by affording two absolutely independent methods of opening the main circuit, one preferably power driven, and the other automatic, the operative relay circuits of which are electrically interconnected so that when once the main circuit is opened it cannot be again closed except under perfectly safe conditions. It would, of course, be a serious objection if provision had not been made for this very possibility.

A MEMBER: Would the fact that a controller was not working be known, and can it be rectified while on the road?

MR. SPRAGUE: Yes, but ordinarily little attention would be paid to it until arriving at the yards. The guards and motormen very soon get used to the equipment. If the controller does not move, they know something is up, and when they pass the despatcher they report that on a certain car the controller is not operating. The train does not stop; it goes on. When the car is in operation, one can open and close the main circuit breakers without any other effect than simply throwing additional load on the balance of the equipment, the counter-electro motive force of course protecting the machines.

A MEMBER: There is one point that Mr. Sprague has not touched on, I think, and that is the cost of maintenance and operation of this intricate automatic mechanism, and the cost not only at the end of one year, but at the end of ten years.

MR. SPRAGUE: Wherein lies the so-called intricacy of system? It is largely a matter of imagination, as can be readily seen by the most casual inspection of the actual apparatus. Let us consider it for a moment in detail.

First, as to motors, we can go back to street precedents. There is not a car running in the city of New York, and few in the United States, amounting, perhaps, to 40,000, but that has two motors and two main controllers. The motors are identically of the same character and general construction as those used on the South Side Elevated Railroad, and differ only in size. Certainly so far as depreciation of motors and gears are concerned, it should be less than on ordinary street cars, because the motors are out of the mud and they are better protected, and the duty is less severe, for they do not stop and start so many times.

I have heard this bugaboo raised many times, but really it is hardly serious enough for me to pay any attention to it, nor indeed for any one else who is familiar with modern motor construction and use.

There is only one main controller on a car, instead of two. The ordinary working parts, that is, of the model before you, are identically the same as those of an ordinary controller. Consequently there is nothing so far which introduces a new factor, and whatever the practice is on street railways is certainly good on an elevated or suburban road.

As to the pilot motor and its limits, what, may I ask, is the depreciation on a fan motor which runs oftentimes 24 hours a day, and in the most out of the way and forgotten places? The construction of this pilot motor is practically the same, only better. There is nothing reremarkably unique about it. The contacts which interconnect its circuits carry the same current as the master controller and the train line and jumpers, the fraction of an ampère.

The master controller has two moving parts, a removable handle and a cylinder formed of two castings, and some contact fingers of an ordinary type.

The relays could not well be simpler. They are plunger magnets, the cores carrying loosely mounted self-adjusting copper discs which impinge against rigid contacts through which are made the pilot motor circuits. Surely one cannot speak seriously of great depreciation in apparatus of this character.

The wiring of a car is actually simpler than on an ordinary street car, there being less work and less material. The train line is of permanent character, much like that of the lighting circuits, and there is only one set of main motor cables.

As to the jumpers, I have already said we have had some trouble with the breaking of wires, caused by mistakes in the early practice of making up the cables. Practice, however, has taught the trick of making these right, but how they are really constructed is a matter I prefer not to at present discuss. I think it may be fairly said that there is less liability to trouble with them than with an ordinary air hose.

Speaking generally, there does not begin to be the complication there is in an automatic air brake system, and yet I do not hear any one inveighing against its practicability.

As to ordinary inspection and care on the multiple unit system, one man can easily look after the master and main controllers and circuits of 25 or 30 cars.

Mr. Blood: It seems to me the argument has been motor for motor and controller for controller *per se*. Wouldn't it necessarily be that if you had ten motors and twenty controllers that you would be liable to have proportionately more trouble than with four motors and two controllers in proportion to the number of instruments?

Mr. Sprague: Possibly I am more of a railway than an electrical engineer. To my mind there is something more to be sought in railroading than the saving of a pound of coal or a dime in inspection or repairs. It is to catch the passenger's nickel, and it does not take much variation on a road to determine its success or failure. If you put the abstract question of whether it is cheaper to take care of one motor with one controller than several, that is of course in general true. It would cost less perhaps to have one chair in this room for everybody to sit on, but it would not be so convenient. You cannot operate a railroad under a flexible system which gives you absolute independence in train units and train intervals unless the cars stand on their own bottom. They cannot be pulled around by the head by something else. To borrow a phrase, we cannot much improve on the Creator. A caterpillar's legs were not put under his head with instructions to drag his body behind him. He gets along, not on all fours alone, but on all multiples.

The proof of the pudding is in the eating thereof. Despite all the dismal prophesies of failure—and there were, as you are well aware, plenty of them—we have been running sixteen thousand to twenty thousand miles a day, and performing a service unequaled in electric railroading.

There seems a curious misconception of the practical requirements of railroading, a tendency to make it simply a problem of moving a fixed length of train a certain distance. The railroad man has not simply a clear and exclusive right of way from one point to another with the necessity of all people to come, because if he has a good thing another man will come along and build another railroad alongside of him. Consequently the manager who proposes to keep the passenger has got to give him the utmost facility of travel, the least station wait, the quickest transit, including that wait, from the time he gets on the platform until he gets to his destination, and it is that frequency of service which is absolutely vital to successful competitive railroading. No one would think of operating on Broadway or Sixth Avenue a six-car train at six times the interval of their present cars. Some day, because of the congestion of traffic, they will probably have to operate two cars together, otherwise a longer unit, but maintain the same characteristics of acceleration.

Mr. C. W. Rice: I should like to inquire the relation of the storage battery to the success of the multiple unit system.

Mr. Sprague: It is not a necessity for the success of the multiple unit system. There are a good many railroads running independent cars without a storage battery. We all know that in any system of transmission of power the more even the output the better it is for the central station. The South Side road ran for a long time without any storage battery, which was not proposed as a part of its original equipment.

The central station was laid out for a larger equipment than was first installed.

The road actually required 145 to 150 cars in operation, including those on the Loop, but not including cars on reserve, which ordinary conditions of painting and general repairs determine as at least 10 per cent., and some think even more, of the total equipment of a road. Only 120 cars were equipped, and the road ran under these conditions until finally there were about 150 cars, including 30 partially equipped cars, in operation, more than there was central station capacity for. Consequently they finally concluded that the quickest way to get additional capacity was to put in a storage battery, which would help to equalize the load and to take a part of the peak. I would say in general, however, that the introduction of a storage battery is advisable on any elevated or suburban road, and, in fact, on any electric railroad when its capacity is to be increased.

No one here should misunderstand the position I have always taken with regard to the storage battery. For a long time it was an impracticable piece of apparatus, but when people got tired of fighting patents, and, with a fund of increased experience, settled down to build a practical battery, realizing that its proper function for railroading was, as I have time and again stated, primarily for regulation, that is, for quick charge and discharge, and for use on peak loads for short time duty only, then it became a safe and advisable adjunct to a railroad when put in under proper guarantees.

The question about the storage battery seems to have been asked because of the impression that on a multiple unit system there is necessarily a large current input on a train, which system *per se* as ought to be perfectly evident, has nothing to do with it, because properly it is simply a semi-automatic system of control which permits of the aggregation of a number of transportation units. That aggregation does not fix the rate of current input, and for any ordinary schedule, no matter what the weight on the drivers, a less than the maximum rate of acceleration can of course be adopted. The speed of the main controllers is not a fixture. The current input is determined by an adjustable throttle which. whatever the carelessness of the motorman, permits of any predetermined slowness in the rate of acceleration, and whatever the maximum rate allowed, it is still possible for a motorman to adopt any lower rate at will. In fact, finer and more even gradations of current input is possible where dealing with smaller currents on individual main controllers than where the whole is aggregated in one large one, as determined by the practical limitations of construction.

Mr. Blood: I am very well aware of the schedule and the frequency with reference to the operating, and also the fact that if you have a system which operates at 50, 60, 70 or 80 per cent. of the income, that it pays in every case to do anything to increase the service, as long as the ratio of the expense per unit of service does not go to a greater extent than a percentage of the expenses to the operating receipts. But the point is, do you not claim a great many things for the multiple unit system, as a system, which accrue to the system, not on account of itself, but on account of the increased speed which you get? For instance, in the Chicago South Side you have ten motors of 50 H. P., each of which makes 50 H. P. If you put the same amount of power on the front car of the four 125 H. P. motors you can get the same pounds per ton and the same acceleration and same speed.

Mr. Sprague: How are you going to do it? How actually make use of the power available?

Mr. Blood: For instance, the present Metropolitan West Side has two 100 H. P. motors on the front car, and they have made a schedule speed of 12½ miles an hour. They never slip the wheels under ordinary acceleration, and they run up to 55 or 60 pounds per ton. If you put on four motors of 125 H. P. you will get the same torque, the same pounds per weight of train as you get now with 10 motors, and you would have therefore the same schedule speed. I believe the South Side runs on a little less than 15 miles schedule speed.

Mr. Sprague: They run at 16½ miles when they have to.

Mr. Blood: But I mean the regular schedule on the road is a little less than 15 miles, and the regular schedule of the Metropolitan and Lake Street roads with the two motors, which handle three cars, is a little over 12 miles. It seems perfectly feasible if you put four motors and increase the capacity of each motor 25 per cent. that you could get the same schedule as you do now with the South Side trains.

Mr. Sprague: You seem to forget that when you concentrate the capacity of motors, be it 500 or 600 H. P., whatever you please, on one car of a five or six car train, you have not the same ratio of weight on the drivers, and consequently you cannot get the same effective pull. That is impossible, unless you pile pig lead into the car.

Mr. Blood: Of course the same weight is not on the drivers, but if sufficient weight is on the drivers to get the pounds per ton which you get now in your schedule, sufficient is enough.

Mr. Sprague: I think I will "stand pat" on the proposition that for all round duty you cannot count on more than 15 per cent. adhesion of steel against steel, and that there are many times, in fogs and other conditions, when you do not get that. It is always advisable to have a reserve. You should be able to slip the wheels even on the South Side road, as we sometimes do, with 62 per cent. of the total weight of the drivers. If you should take a locomotive car and put on it four 125 H. P. motors, you can slip the wheels as long as you please and you will probably not break down the motors, but you do not reach the practical limit of acceleration which is comfortable. I care not how fast it is, so long as it is done evenly, there is no rate of acceleration possible even with 100 per cent. on the drivers, which is not perfectly feasible so far as passengers' comfort is concerned, but it must not be by jumps, but with a controller that is properly built, graded and regulated.

Mr. Blood: I perfectly agree with that statement, and I also do not wish to be understood as an opponent of the advantages of the multiple unit system. But what I do wish to bring out is that the point at which the system gives advantages on account of its increased acceleration is far above that of any system that has been used now. I worked at a multiple scheme in connection with some propositions in Berlin and Vienna, and it might be interesting to know that the scheme proposed by the German companies was with a locomotive at each end of the train.

Mr. Sprague: I think quite likely I can tell you something about it.

Mr. Blood: And the chief advantage of the multiple system is the advantage of the splitting up of the train, and not so much at the present time the advantage due to acceleration, because the point is not reached in the present schedules where the advantage will show up.

MR. SPRAGUE: I quite agree with you about splitting up trains, and I think I said quite clearly that I considered the question of coal economy, which for any given schedule is primarily affected by the rate of acceleration, is a thing of less importance than independence in determining lengths of train units and train intervals. The higher schedule speeds for all combinations are, however, only possible with the high acceleration, and hence necessary high ratios of weight on drivers. I must, however, repeat the statement that for any given high schedule the system which gives the highest rate of acceleration is the cheapest system to install in total first cost, as well as the cheapest to operate. It costs anywhere from $200 to $250 per kilo-watt for the energy delivered to the shoes of a car. It costs from $15 to $20 per H. P. for the equipment put on a car, including every detail on it. I am speaking in a general way. Therefore if you can save 1,000 H. P. in a large central station you can afford to put a good many thousand H. P. on the cars, and besides you are going to gain a good deal else by doing it.

Referring to the Berlin proposals, it has been only comparatively a few days since I received a letter from possibly the German firm you referred to. It was quite explicit as to the plans hitherto considered. Their plan of operation—and they are somewhat in the air about it—was to operate four-car trains normally with two dead intermediate cars and one locomotive car at each end, each motor car having four motors, the motors to be worked in two groups, two being permanently connected in series, and these two series groups worked in series and multiple; that is, on a four-car train, eight motors, every pair maintaining a fixed relation. The main current was to be carried from one car to the other, and a hand control provided for all motors at each end of the locomotive cars. In stopping it was proposed to use the forward car alone for an electric braking system. Realizing, however, that there are times when the traffic would require more than four cars to the train, they were contemplating a possible method of combining two of these four-car eight motor trains into an eight-car train.

The difficulties experienced were leading them to inquiries into the multiple unit system, which is the straightforward logical development, and in every way simpler and more effective.

Now I have had a modicum of experience in electric railroads, and I am quite ready to let some other men try all sorts of alternative combinations. Evidently these engineers recognized the fact that they had to use a large proportion of the weight on the drivers, large motive powers, and hence distributed motors, and that is what they are proposing to do. That happens to be an official statement of facts from the firm which has the contract under consideration.

MR. BLOOD: The reason that they were to use the two ends of the train was that the German government specified that the control must be from the end of the train which it was operating. The first road which the Siemens people were to try it on was the Wannseebahn, and at one end they did not have the opportunity for switching. I figured out a scheme whereby they could; but the German government decided it could not be done, and so they wanted it done that way. I do not think that they considered the distribution of the motors, and the reason they would not allow braking on the rear car was because they were afraid that the train would double up together in the middle.

MR. SPRAGUE: In other words, they ran across a lot of difficulties the moment they attempted a combined locomotive car system. One of the good things the German government does is to put down certain restrictions. Really the broad issue is between a secondary control and an attempted control with main circuits running from one car to another. I am quite content to rest on that issue.

MR. H. WARD LEONARD: It seems to me that one of the most important points in connection with the question of elevated practice, as has been clearly brought out by Mr. Sprague in his remarks and by many others heretofore, is the fact that a very rapid acceleration is a necessity, and that having stored up in the train a very large amount of energy represented by that acceleration, it becomes necessary with the practice which has been described to waste that energy on the brakes, and it seems to me that there are great possibilities in providing for the return of this energy to the line.

MR. SPRAGUE: The maximum speed at which a train is braked is what determines the amount of energy thrown away, and we reduce the kilo-watt hours per car mile by keeping that maximum speed as low as possible. On the South Side road our miximum speed if often only 50 per cent. higher than the schedule. We actually do a great deal of coasting. On many runs the current consumption at the car shoes is only 1.55 per kilo-watt hours per car mile, or from 70 to 75 watts per ton-mile under the conditions there existing. I have, in common with all others who are interested in this sort of subject, considered the return of the energy that still remains in the car at the time of braking to the line. Of course there are quite a number of methods of doing it. Mr. Leonard no doubt has one in his mind. I have had several, and in experiments which were tried on the 34th Street branch of the Elevated in 1886 and 1887 I used shunt machines, and weakened the field to increase the speed, and in slowing down strengthened the field to send current back to the line. That brought the speed down comparatively low. Then the current was thrown on a local rheostat circuit, and the train stopped without any mechanical brakes. But the series motor has certain advantages, one being its tremendous overload capacity, and others its speed and commutating characteristics. These have led most railroad engineers to use it for the actual conditions of railroad practice, and to abandon the project of putting current back into the line.

Coming back now to the question of schedule speed, high ones, with stations only a short distance apart, are only possible by using a high rate of acceleration, and it is impossible to get it except with high weight ratios. Take, for example, the Manhattan road in this city. Its stations average a third of a mile apart. It is making now 12½ miles actual schedule during the time of maximum load, averaging its entire runs. On Sixth Avenue below 50th Street and on the lower part of Third Avenue its schedule speed sometimes gets down to 11 miles per hour, although the average is brought up to 12½ miles. It is possible on that road to make a schedule of 17 miles with only two motor equipments per car, although that is pretty nearly straining the limit, but it is quite practical to make over 16 miles, in other words, to bring Harlem abreast of Central Park; that, too, without exceeding the present maximum speed of trains, and with a reduction of the strains on the structure, which has concerned our city officials a great deal lately, but which does not trouble most of us who travel on it. It is possible to exceed 16 miles schedule with only about 25 or 26 miles maximum speed, at not exceeding nine cents per car mile total operating expenses, as against 11.9 or 12, their present cost. Since they make about 43,000,000 miles on their present service; that means a saving of about $1,300,000. I do not know what their equipment would, or, rather, will cost; but after paying a very fair interest on that cost there could still be a satisfactory surplus to the good. All this, of course, is on their existing passenger service, without regard to what it might become with an improved condition of operation.

Mr. Armstrong: I would like to ask if the rate of acceleration Mr. Sprague is using on the South Side elevated is demanded by the necessities of the schedule of speed he is getting there; that is, if the multiple unit system is needed for a schedule speed of fifteen miles he is making.

Mr. Sprague: It would be possible to make that schedule with fewer motors and more concentration. They could not, however, make the schedule which they will be driven to. Remember, Mr. Armstrong, a road has not always got its path cut out as its representatives would like. You have lately been a somewhat strong advocate of an increase in the rate of acceleration. You have published a number of curves which show the economy of that method of operation. I am quite content to accept some of them as reliable and as authoritative. There will be, at times, conditions of track, of train congestion, and delays in coming out of the Loop or getting away from stations, such that it will be necessary to call on all the reserve power in a train, and to force the motors to the limit of capacity and wheel adhesion. Referring to the Metropolitan road of this city, somebody once made the remark that spared nothing in expense to insure continuity and certainty of service. That is good engineering and sound commercial sense. That you shall get your passengers through, and safely, is the first requirement. That you shall get them through at the highest rate of speed that you can practically, if you are in competition with another road, is a second one. There was a good many predictions of failure of the South Side road. Possibly you remember them. The company which you represent refused absolutely to take any responsibility in connection with it. It was willing to sell me 240 motors and a good deal of other apparatus, amounting to a considerable sum of money. But its orders were strict to its engineers that no responsibility for performance other than for guaranteed H. P. should be entered into. I would a little rather not mention some of the incidents attending the putting in of the South Side equipment, but I am free to say that very cordial predictions of absolute failure were made in respect to it.

Mr. Armstrong: Was a time limit set?

Mr. Sprague: No, thank you, not much. Twenty-four hours were given after the rheostats which I bought failed me, resulting in a burned-up car on the road. I think that I stated that we had more trouble with that which is sold as standard apparatus than we had with the apparatus of the multiple unit system, and that trouble is not finished yet, as, for example, on such a simple thing as gear cases.

Mr. Armstrong: That constituted 90 per cent. of your apparatus.

Mr. Sprague: The apparatus we bought in various ways.

Mr. Armstrong: You naturally expected that 90 per cent. of your trouble would come from it?

Mr. Sprague: No. I am not speaking of the money amount. It is a good deal more. But I am speaking of the physical troubles—the things which would cause delay and worry. On the first day I started, with twenty cars, seventeen were suddenly taken in because I saw one car going down the road in flames. The trouble was that too thick German silver strip was used in the rheostats, which were not of my own manufacture. Where it was bent around an angle it was fractured; they open circuited, shot out a flame and set fire to the car. I was worried for a little. I pulled off seventeen cars and kept three on, and helped boost a locomotive and train around a curve, but this trouble was rectified.

But temporary troubles characterizing the early development of a new system are in the nature of children's diseases, soon discarded for man's estate.

You, Mr. Armstrong, and every other engineer interested in serious electric railroading, must sooner or later come to the unqualified indorsement of the multiple unit idea. Please remember that prophecy.

Already your company, as well as others, are swinging that way, as is evidenced in the former's April bulletin on four motor equipments for pivot truck suburban cars, wherein the advantages of high tractive effort and quick acceleration are set forth, four motors are recommended instead of two of the same aggregate capacity, and the efficiency and relative cost of maintenance are stated to be about the same.

What are the new electrical and commercial conditions which, when the aggregate of traffic makes necessary the grouping together of such cars into trains, a time when the demands are surely no less, lead to a reversal of engineering conclusions?

Again, for train operation, 2 4-motor locomotive cars, with synchronous control, have been recommended more than once, and what is this but a mongrel kind of multiple unit system?

It is impossible to stem the advance. The locomotive car, as well as the electric locomotive pure and simple, is doomed for the class of electric railroading we are considering.

I think I may fairly say that I have not recorded many failures in prophecies on electric railroading, and I have been making them for sixteen years, during which I have never hesitated to back a prophecy with every dollar I had, and also what my friends saw fit to add.

Mr. Armstrong: I would like to ask another question of Mr. Sprague.

Mr. Sprague: I am a good subject.

Mr. Armstrong: He spoke of the facility with which you could make up a train with a multiple unit system; that any car could be put in any place in the train —that is really for information. I want to know how they manage with the smoking cars in Chicago, whether you keep one car there as a smoker or whether you can use any car as a smoking car?

MR. SPRAGUE: On the South Side road certain cars are marked smokers, and used as such.

MR. ARMSTRONG: They occupy a certain place in the train?

MR. SPRAGUE: I don't know what their present practice is. Perhaps Mr. Shepard can say.

MR. SHEPARD: One end or the other.

MR. SPRAGUE: I hope the time will not come in New York when cars will have to be provided for smokers.

MR. ARMSTRONG: I simply want to make the point that you cannot make up a train with utter disregard of any car constituting the train.

MR. SPRAGUE: I do not mean that if you had a parlor and a baggage car and wanted to keep them in a certain order you could change their character. What I did wish to emphasize was a condition of actual practice, and the fact that so far as control is concerned the end relation or sequence of cars is a matter of indifference.

The South Side Elevated Railroad has a loop at one end, an open ended relay at the other, and a yard somewhere between from which cars can go out in either direction. It is therefore absolutely certain that as cars are made up into trains, and as they are inspected or repaired, they get mixed up, that is, it is impossible to maintain any fixity of relation between them. To-day, for example, the motor ends of two cars may be similarly headed, but to-morrow one of them may be reversed and another car introduced between them, and so on.

Curiously enough, this fact seems to have been ignored by every one of late who has been attempting to devise a multiple unit system.

The yard man who makes up a train is not an electrical engineer, nor a doctor of physics. He does not carry around a kit of testing instruments, nor a book of diagrams, but oftentimes amuses himself by hammering the track with a jumper, or in making unquotable remarks. Nor is the motorman a scientist. What they both must know is that when a train is made up, and the handle of the master controller is moved in a certain direction relative to the platform, that that motion is followed by a certain corresponding track movement, and with the least possible thought or calculation on any one's part.

MR. ARMSTRONG: I think you rather digress from the point I was trying to get at there; that is, if a train consisted of a motor car and three or four trailers, the motor car would occupy nearly the same position your smoker does, and the trail cars would be in the same position as your other motor cars.

MR. SPRAGUE: In other words, you would subordinate the road to the necessities of the smokers.

MR. ARMSTRONG: No.

MR. SPRAGUE: As a matter of fact, they run the smokers in that particular case at either end of the train.

MR. SHEPARD: The smoker cars are distinctly marked.

MR. SPRAGUE: Of course, I expect arguments against the multiple unit system, even if they must be oftentimes trivial. I cannot hope to have everybody agree with me, but I find a good many who are coming that way as fast as their dignity or associations will permit.

MR. ARMSTRONG: I was asking for information, I was not arguing.

MR. BLOOD: In connection with the question brought up in reference to the return of power to the line, I would like to bring up a point which came rather curiously in figuring on a road. It was a constant 5 per cent. grade. I said to myself, here is a good chance to figure on a system of putting power back into the line. There was only about fifteen per cent. of the whole road that was level. In the scheme I figured out I found that, owing to the fact that the efficiency doubles on itself—that is to say, in putting the power into the train you could not get greater than 70 per cent. efficiency from the line to the rail—that is a good high efficiency under ordinary conditions, that is, running conditions; but including the stops, if you get 70 per cent. that way and 70 per cent. the other way, the most you can save is 49 per cent., and I figured out in this case, taking the whole thing into account, that the amount of power saved, even though we were going to use water power (but we had to use storage batteries), that the extra expense would not equal the amount saved—the interest of the extra expense. If you remember, in connection with this system, one of the diagrams which Mr. Sprague had on the chart here the braking point is much less than the economical point of speed, and when it is remembered that the energy varies as the square of the speed, and when it also is remembered that you must take something less than 40 per cent. possibly saved of the total figured out, that the amount that you save in the brakes—the amount of energy that is in the brakes, and the amount of energy that could be saved in the brakes, is an insignificant amount of the total energy used—something less than 10 per cent.

MR. LEONARD: I think that it is a little out of the line of discussion to debate a point of this nature; but I will just say briefly that I think the last speaker has made a slight error in assuming that if you did restore energy to the line the proposition would be true that it would be an economy to operate at very high acceleration and then coast; because the entire argument in favor of coasting as an economy is based on the proposition that you cannot restore energy to the line, and if you could operate with a system which did restore energy to the line the result would be that you would avoid these very extraordinary peaks of energy and reduce greatly the capacity of your plant and the amount of energy in kilo-watt hours that is used. Of course, it is entirely correct that you could not save more than 50 per cent. That is quite readily granted. But I think 50 per cent. is a great deal.

MR. SPRAGUE: Fifty per cent. cannot be saved. It is impossible.

MR. BLOOD: Fifty per cent. is the theoretical limit.

MR. SPRAGUE: You have not only got the train under way, but you have to carry it over the road. What you can put back on the line is actually measured by what the speed of the car is at the point of braking. The quicker you get under way, the less the maximum and the braking speeds.

MR. LEONARD: Your speed should be the highest when you put on the brake, if you restore anything to the line.

MR. ARMSTRONG: In this case the duty on motors would be double, and the first cost of the apparatus per car, instead of $15 to $20 per kilo-watt would probably be $30 to $40.

MR. LEONARD: If the power is cut in two, you would have a pretty big saving.

Mr. Sprague: There is a field for somebody's energy. I have been trying for fifteen years to find a practical method. I have never found one which would warant the expense. The conditions of railroading are arduous. The speeds are variable, they are not constant as they are in certain classes of power service. I must confess that on railroads power return has generally been a failure. I have given up much hope of returning energy to the line, that is, from a commercial standpoint. It is possible from a theoretical one.

Mr. Leonard: I should like to ask Mr. Sprague if he can give us any information, whether he is at liberty yet to give information, as to the methods by which he obtains the end to end turning of the cars without confusion.

Mr. Sprague: I should rather be excused. It is a point which has generally been overlooked. Of course it lies in a fundamental system of connections. It is scarcely a thing which I can hope to keep to myself; at the same time I would rather do so for the present.

Mr. Blood: I would like to have, as a matter of record, what speed it is thought we will have to resort to in multiple units to get a higher acceleration.

Mr. Sprague: You mean what is possible?

Mr. Blood: No. When it becomes necessary to change from the locomotive system to the multiple unit system in order to get the schedule speed.

Mr. Sprague: I cannot answer that off hand. It is simply a question of kinetics. It depends on grades, curvature, distance between stations and length of train. As I said a moment ago there are a good many questions involved besides schedule speed, questions of flexibility of service, distribution of weights, strains, etc. It is really a comprehensive engineering question on any road. When a man starts out he should determine what he wants, and then adopt the most effective method of getting it.

The President: If there is no further discussion a motion to adjourn is in order.

On motion the meeting adjourned.

CHRONOLOGY OF MODERN ELECTRIC TRAIN OPERATION FROM 1880 TO 1899

1880.—Edison built and ran at Menlo Park an electric locomotive, and subsequently designed some others.

1883.—Daft at Mt. McGregor ran the Ampère, pulling one car, and Field, at Chicago, the Judge, also pulling one car.

1884-5.—Vandepoele at Toronto, and later in 1885 or 1886, at Minneapolis pulled trains of cars with an electric locomotive.

1885.—Daft, at Baltimore, operated a locomotive and trail car, subsequently increasing the equipment, and on the Elevated Road pulled a train with an electric locomotive for experimental work.

December, 1885.—At Society of Arts, Sprague stated some of the possibilities on the elevated railroad, and pointed out the advisability of putting motors under each.

1886.—Sprague built the first locomotive car. This was intended for experimental work on the Elevated Road, but was abandoned before the motors were completed.

1886.—About this period the Rhode Island Locomotive Works, under direction of Knight & Bentley, designed a locomotive for rapid transit train operation, but it was not built. About this same time Stephen J. Field designed an electric locomotive for the same purpose.

1886-87.—Sprague operated a standard elevated railroad car with two single reduction motors, axle centered, and with one end spring supported from the truck body, on the 34th Street branch of the Elevated Railroad and also pulled a trail car, and prior to this, a platform car with the same motors in the Durant Sugar Refinery on 24th Street, New York. This was followed by the Richmond equipment, the beginning of the modern development.

November 4, 1890.—City & South London road opened. Originally designed for cable. Light trains operated by electric locomotives having two gearless motors with the armatures rigidly mounted on the axles of drivers.

1892.—Sprague, Duncan & Hutchinson designed, afterwards building it, a sixty-ton electric locomotive for experimental work in connection with the North American Company. It was not put to use.

February 4, 1893.—Liverpool Overhead Railway. Operates two-car trains, each car having one motor disposed at the leading and back ends of the couple, the two cars being kept together as a unit. Hand control at each end.

Spring of 1893.—Under the general supervision of Mr. W. E. Baker, assisted by Mr. B. J. Arnold in charge of the steam plant, and Mr. Charles H. Macloskie in charge of the car equipment, the Intramural Railway was constructed at the World's Fair. The General Electric Company were largely interested in this enterprise. Four-motor cars, with hand control, were used to pull three trail cars, this plan of distributed motors under the passenger car having been advocated by Mr. Baker in opposition to the general opinion then in favor of electric locomotives. The third rail supply with the flexible sliding contact shoe, was here used for the first time, and the road may be said to be the first real practical train operation on any serious scale in this country.

November 3, 1893.—The General Electric Company's engineers in a communication to Colonel Hain, general manager of the Manhattan "L," recommended eight-car trains to be pulled by a single forty-ton four-motor car, guaranteed an increase of 14 per cent. in schedule, and stated that the motor car could pull thirteen-car trains as easily as present steam locomotive could pull five cars.

Proposed potential of about 600 volts, direct supply, unspecified number of stations, and did not suggest alternating currents, boosters or storage batteries.

May, 1895.—Metropolitan West Side Elevated Railroad equipped under the supervision of

Mr. W. E. Baker, and using General Electric Company's apparatus, opened on locomotive car plan, using two motors on locomotive cars. This was the first commercial elevated road put into operation in the United States.

June 27, 1895.—First of three ninty-five-ton locomotives put in operation in Baltimore, by General Electric Company for pulling freight and passenger trains through B. & O. tunnel.

September 20, 1896.—Lake Street Elevated Railroad, which had been operated since October, 1893, with steam, began electrical operation, plans similar to those on the Metropolitan.

February 1, 1896.—(Daily paper.) Electric Storage Battery Company of Philadelphia, described and proposed a storage battery locomotive to pull trains, storage batteries to be used in combination with current from third rail.

February 8, 1896.—(Daily paper.) Sprague, in reply to strictures on the capacity of electric motors in a daily paper, offered, under $50,000 forfeiture, to equip a train which could be pulled by a locomotive car, and also by motors under each car simultaneously controlled, and to make a speed of forty miles an hour on express service.

April 17, 1896.—In interview in daily paper, Westinghouse, on behalf of the Westinghouse Electro-Magnetic Company, with what was called the Westinghouse-Wheelless System, proposed for all elevated and suburban roads the use of a contact pin system and the continuous current. At the same time it was stated that in ten days public demonstration was to be made to demonstrate the success of the Tesla alternating current motor for this purpose.

July 16, 1896.—Exhibition by Westinghouse of contact pin system, made for benefit of Manhattan officials.

June 6, 1896.—Sprague proposed to Messrs. Gould, Sage and Galloway, special committee of Manhattan Elevated, to make demonstration equipment of multiple unit system.

May, 1896.—Nantasket Beach Railroad put in by the N. Y. and N. H. R. R., under the supervision of Colonel Heft was opened—used General Electric apparatus and a locomotive car carrying passengers and pulling a trail car.

November 29, 1896.—Under the supervision of Mr. C. B. Martin, electric service was instituted on the Brooklyn Bridge R. R. Twenty motor cars, each equipped with four General Electric Company sixty-two and one-half H. P. motors, and hand control replaced the steam shifting engines, and were used in connection with the cable.

December 10, 1896.—The General Electric Company through its western office, proposed to the South Side Elevated Railroad an equipment of three and four-car trains, one of which should be a locomotive car having two motors, and six-car trains, one of which should be a locomotive car having four motors, guaranteeing that on the first combination thirty-five miles an hour could be made, and on the second forty-five miles an hour between stations 2,000 feet apart. No central station system was described, either alternating or continuous, or any potential determined.

December 10, 1896.—The Walker M'f'g. Company proposed to the South Side Elevated Railroad a system as follows:

Continuous current, station in middle, pressure 600 volts, three and four car trains, one being a locomotive car having two 125 H. P. motors, and guaranteed to save seven minutes in the trip from Congress Street to 63rd Street, a distance of about eight and one-half miles, that is, to make a schedule of nearly nineteen miles.

February 14, 1897.—Sprague again stated the possibilities of the multiple unit system to the Manhattan Road, and again offered to make a demonstration equipment and to work up to eight-car lengths under every possible condition.

February 25, 1897.—Sargent & Lundy reported on general equipment for South Side Road, giving summary of locomotive car proposals and their recommendation, one of which was to double up trains.

February 26, 1897.—Potter, engineer of the railway department of the General Electric Company, reported to the third vice-president at Schenectady his recommendations of a system for the Manhattan Elevated, with details as follows:

Direct current, three wire system, the cars on one track being in series with those on the other, 650 volts on each line, and 1,300 volts between power rails on the two tracks, the track rails to be used as the neutral wire; two power stations equipped with 2,300 kilowatt generators, direct current supply; five car trains to be pulled by a single motor car with four motors; possible boosters or storage batteries at South Ferry alone; no alternating current, no sub-stations proper, and no storage battery regulations at sub-stations.

About the same date, a system diametrically opposed in almost every essential was proposed and recommended to the general contractors for the Central London Railway by Mr. Parshall of the British Thomson-Houston Company, with the General Electric Company in consultation as sub-contractors.

This proposition opposed the three wire system, and on about six miles of road recommended alternating current machines, four sub-stations with rotary converters, no storage batteries, five-car trains pulled by electric locomotives pure and simple instead of locomotive cars. The locomotives are now being built and weigh forty-five tons each. The schedule is moderate, and acceleration and braking are aided by having the station at peak grades of from two to three per cent.

The Westinghouse Company made proposals of something the same nature, and the Siemens-Halske proposed the three wire system, one track being in series with the other.

March, 1897.—Sargent & Lundy issued general specifications calling for alternative proposals for:

Thirty-six locomotive cars each having four 125 H. P. motors.

Forty-five locomotive cars each having two 150 H. P. motors.

One hundred and twenty motor cars each having two thirty-five H. P. motors.

April, 1897.—General Electric Company through W. B. Potter, engineer of the railway department, proposed to the South Side Elevated Railroad four and five-car operation, one car being a locomotive with four motors.

April, 1897.—Westinghouse Electric & Manufacturing Company proposed to South Side Elevated operation of five-car trains, one being a locomotive car equipped with four 125 H. P. motors, and guaranteed to make an eighteen-mile schedule.

April 7, 1897.—Sprague as consulting engineer condemned the locomotive car system for South Side road, and recommended the adoption of the multiple unit system.

April, 1897.—Messrs. Sargent & Lundy, after report by Sprague, abandoned the locomotive plans for the South Side Elevated and fully endorsed the multiple unit system.

April, 1897.—Chief Engineer Wallace, of Illinois Central Railroad stated that trains should be run in any length from one to a dozen cars and he hoped to be able to run them with a push-button.

April 17, 1897.—Sprague tendered to the South Side Elevated Railroad a proposal to equip 120 cars on multiple unit system.

May, 1897.—Chief Engineer, George B. Cornell, of the Brooklyn Elevated Road, stated that two essentials of his endorsement of any change from steam to electricity on that road were increase of schedule speed and a control which could enable him to run single cars or any desired aggregation of cars into trains.

1897.—Short, for Walker Manufacturing Co., and the Westinghouse Company also, proposed various locomotive car plans for Manhattan Elevated.

July 16, 1897.—Sprague made demonstration at Schenectady, of two-car multiple unit train, and ten days later of six-car train.

November-December, 1897.—Sprague made working test of multiple unit train on Metropolitan Elevated of Chicago of five-car multiple unit train.

Fall of 1897.—On the Brooklyn Elevated Railroad, the General Electric Company's engineers recommended for a fifteen-mile schedule four and five-car trains, two of the cars being locomotive cars, each weighing about thirty-five tons and equipped with four motors, with through connections of the main circuits, so that either the four or five-car unit could be operated from either one of the locomotive cars from a hand control. No independent operation of other cars was proposed. An alternating current central station with sub-stations, rotary converters and storage batteries were also recommended.

1897.—Short, for Walker Manufacturing Co., and the Westinghouse Co., also proposed various locomotive car plans for the Manhattan Elevated.

December 23, 1897.—Sprague Electric Company sent the Illinois Central Railroad Company on specifications of Mr. John Lundie, the consulting engineer, a bid for an equipment for the suburban service of the Illinois Central Railroad, to use direct current system, with storage battery equalizers, individually equipped cars, multiple unit system, and to make a schedule speed of twenty-four and one-half miles with stations averaging 2,900 feet apart.

December 23, 1897.—On same specifications General Electric Company made similar bids to the Illinois Central under agreement to get controllers for same from Sprague Company in case their bid should be accepted.

January 12, 1898.—Mr. Sprague proposed to Mr. Gould to operate any combination of from one to ten cars under any conditions of rail on multiple unit system.

February 18, 1898.—Sprague tendered to the Brooklyn Elevated Railroad the multiple unit system. For temporary use, twenty-four equipments were consolidated on twelve cars to be used first as locomotive cars, and afterwards to be distributed.

The motor equipments were to be designed for seventeen-mile schedule with existing station intervals.

Those on the South Side were designed for a fifteen-mile schedule, but make sixteen and one-half at times, with longer intervals.

February, 1898.—The General Electric engineers offered to supply on the first twelve cars actually equipped by the Brooklyn

Elevated Railroad motors with either hand or semi-automatic control, and proposed to supply four or five months later, when developed, a full multiple unit control.

April 20, 1898.—Sprague began operations on South Side road with multiple unit system.

June 18, 1898.—Sprague began operation on the Bridge end of the Brooklyn "L" road.

July 12, 1898.—Waterloo & City, London. Straight run one and one-half miles, no mid-station. Operates light four-car train units, the two end ones being motor cars with two motors, and the intermediates being dead cars.

July 27, 1898.—Multiple unit system in full operation on South Side road, and steam abandoned.

Equipment on South Side road afterwards increased to 180 cars, 150 of which are fully equipped, and thirty, for emergency service, partially equipped.

November 1, 1898.—Westinghouse Company began to put twenty cars on the Kings County Elevated Railroad, each equipped with two sets of two motors with controllers actuated by air pistons and controlled by a secondary electric circuit. Four only out of the twenty cars are in use at present and for locomotive purposes.

1898.—General Electric Company proposed six car trains and double locomotive cars for the Manhattan Elevated, and three car trains with a single locomotive car for the Boston Elevated.

And finally the engineers of the General Electric and Westinghouse companies are credited with the intention to operate experimental multiple unit trains.

Of course, there are a number of other proposals which have been made both for multiple unit and other systems, and for various roads, of which, however, mention is unnecessary for the present.