

DISCUSSION ON "COMPARATIVE PERFORMANCE OF STEAM AND ELECTRIC LOCOMOTIVES", AT NEW YORK, NOVEMBER 8, 1907.

William J. Wilgus: Instead of apologizing for adding to the number of papers on the electrification of steam railroads, the author should feel entitled to congratulations for calling attention to many of the advantages of the electric locomotive that have heretofore escaped analysis. In my judgment the cause is injured rather than benefited by arguments for the wholesale application of electricity to steam railroads, and it is pleasing to note the increasing tendency in our technical societies to sane discussions that will really enlighten the railroad officer anxious to be in the van of progress.

Unquestionably, electricity in heavy traction work has come to stay. As the author states, until now the reasons that have lead to the principal changes of motive power are entirely apart from questions of economy in operation. Conservative advocates of heavy electric traction, while urging its self-evident advantages in the abolition of the products of combustion in tunnels and cities, the increasing of terminal capacities, and opportunities for growth of traffic, have refrained from dwelling too strongly on saving money. They have been contented with the belief that more money could be made. The burden of additional interest charges, taxes, maintenance and depreciation attendant upon the substitution of electricity for the old form of motive power has very properly caused the careful engineer to pause in admitting even to himself that in addition to increased capacity to handle traffic, there might be a net saving in cost of operation. This cautiousness has sprung from the absence, until recently, of any actual data on the cost of heavy electric traction operation.

The pioneer electrical installation in heavy trunk-line service, on the New York Central & Hudson River Railroad, has now been in complete and successful operation since July 1, 1907, the gradual change from steam power having commenced in December, 1906. The working side by side of both kinds of motive power has given unsurpassed opportunities for the observation of their comparative capacity and efficiency. The results are even more gratifying than were expected; and substantiate many of the author's claims of superior capacity of electric equipment, although the conditions differ widely from those that he has assumed.

At this point it may be well to venture a word of caution on the subject of costs. Comparisons are worthless unless all elements of expense that will affect the results, are included. For instance, the cost of current delivered at the contact shoes should include not only costs of operation and maintenance, interest, depreciation, taxes and insurance on the power station, but likewise on the entire distributing system. If this is properly done, the real cost of current, as finally delivered

at the electric equipment, will be found very largely to exceed the usual assumptions. The author's cost of current seems to me to be considerably too low.

On the other hand, the cost of maintenance and care of equipment should embrace not only wages and supplies, but also interest, taxes, insurance, maintenance and depreciation on the structures and real estate required to house and repair the equipment. Steam locomotives require extensive engine-houses, coal and water stations, ash-pits and appurtenances, often on very expensive lands, whereas electric equipment needs the simplest form of inspection sheds occupying limited areas of land. Also steam locomotives require extensive and complicated heavy-repair shops, usually at far distant points, that necessitate costly dead mileage and lengthy idle periods, while electric equipment because of its simplicity can be much more quickly repaired in nearby shops and returned to service. Many of these features have been mentioned by the author, but possibly their importance can be emphasized by giving some concrete examples from actual practice on the New York Central.

Because of less cost of maintenance of electrical equipment, and less idle time in shops, the greater cost of interest charges and depreciation is not only neutralized, but a net saving in repairs and fixed charges over steam equipment is effected of 19 per cent.

Electric locomotive inspection and light repairs, as compared with coaling, watering, drawing fires, repairs, etc., of steam locomotives show a saving in time in favor of the former of over 4 hours per day, equal to 18 per cent.

The electric locomotive, while busy, is a much more nimble and efficient machine than the steam locomotive, showing an increase in daily ton-mileage of 25 per cent.

While not so important in freight service, the question of locomotive weight is a large factor in a comparison of the relative economy of handling passenger traffic by steam and electricity. For instance, in switching service at the Grand Central terminal, 65 per cent. of the total steam ton-mileage is due to locomotive or "dead" weight, while the electric locomotive percentage is but 54 per cent., a saving for the latter of 11 per cent.

In the regular schedule service, the steam locomotive shows 51 per cent. dead ton-mileage as against 35 per cent. for the electric equipment, a saving for the latter of 16 per cent. When we realize that this saving of "dead" ton-mileage has a direct proportionate effect on the cost of fuel and current, and an indirect effect on wages and fixed charges, its importance is manifest.

The author calls attention to the speed advantage of electric over steam locomotives in mountain-grade operation. This is strikingly apparent in the New York Central installation,

where the increase in coal consumption for car ton-mileage in high-speed service as compared with slow-speed service, is shown to be 165 per cent., whereas under exactly the same conditions the increased consumption of current for electrical equipment is but 18 per cent., a difference in favor of electrical operation of 147 per cent.

The net result of all of the economical advantages of electric operation, over steam, *for the conditions existing on the New York Central*, after including all elements of cost of additional plant, shows a saving in summer months of from 12 per cent. to 27 per cent., depending on the character of service. A larger saving may be expected under winter conditions.

In addition to this saving, the nuisances and dangers from smoke and gas in the Park Avenue tunnel have been eliminated, and the capacity of the Grand Central terminal has been increased about one-third. Later when the New Haven Company effects its change of power, complete electrical operation in the tunnel will permit the use of shorter blocks, and correspondingly increase the capacity of the four-track main-line entrance to the terminal.

I feel sure that the author will be pleased to know of this actual demonstration of the correctness of many of his views, and that the members of the Institute, regardless of their advocacy of rival systems of electrification, will take pride in the successful inauguration of this pioneer trunk-line installation, on such a large and complicated scale.

It might be well to add to the author's keynote *capacity*, the equally important one of *efficiency*, as the two combined, applied to the problem under consideration, will demonstrate whether or not the adoption of electricity is justifiable from the standpoint of economics.

Cary T. Hutchinson: I think that Mr. Armstrong gives the clearest statement of the capacity of steam and electric locomotives that I have seen. I agree with Mr. Armstrong that no project of electrification of trunk lines has up to the present been undertaken from an economical point of view. The matter has so far been determined by special considerations, such as the terminal problem in New York City, or the mountain-grade problem, or something similar. I doubt whether there are sufficient data on hand to permit the making of an accurate estimate of the total annual cost of electrical operation of any steam road; all data on the subject that I have seen are subject to criticism from one point of view or another.

Mr. Armstrong considers especially two points; the relative capacity of steam and electric locomotives as machines, and the relative cost of operating the two. I think, however, that he does not emphasize strongly enough one feature of the capacity of electric locomotives, that is the capacity in *continuous service*.

Regardless of the type of motive power, the design of a locomotive is limited to a certain weight on each driving axle, the

maximum being about 50,000 pounds; the coefficient of adhesion, as Mr. Armstrong states, in steam locomotive practice is taken at about 22 per cent. Each driving axle will then be able to deliver a tractive effort of 11,000 pounds, and a draw-bar-pull of, say, 9,000 pounds. A steam locomotive can exert this draw-bar pull continuously, up to a certain speed determined by the capacity of its boiler, which for the sake of illustration may be taken at eight miles per hour, so that in freight service each driving axle will give a continuous duty of 9,000 pounds. Owing to the limitations of space, no electric locomotive can be built to deliver continuously a draw-bar pull of 9,000 pounds per driving axle; probably 5,000 pounds is the maximum that can be obtained; that is to say, an electric locomotive cannot work *continuously* at a coefficient of adhesion greater than about 12 per cent. Therefore, for continuous service at low speeds a steam locomotive, for the same weight on drivers, can pull from 60 to 100 per cent. greater load than an electric locomotive.

The electric locomotive can, however, deliver this draw-bar pull at any speed that it is practicable to use, the limitation being fixed by the equipment and the track, and not by the locomotive. The draw-bar pull of the steam locomotive falls off from the critical speed of, say, eight miles per hour, as is well brought out by Mr. Armstrong in the paper, whereas an electric locomotive, designed for the purpose, will give its continuous drawbar pull at any practicable speed; hence, at a certain higher speed the two locomotives will pull equal loads continuously, at say about 16 miles per hour. At all higher speeds the electric locomotive will have the advantage.

The size of an electric motor is determined principally by the torque that it must exert and not by the speed at which it must exert this torque; hence a locomotive designed for 10 miles per hour and a draw-bar pull of say 5,000 pounds per axle, can, by changes in the windings, which will not change the size or weight of the motors, exert a draw-bar pull of 5,000 pounds at 40 miles per hour, or any other practicable speed. This is the great advantage of electric as compared with steam locomotives.

Another way of looking at the matter is that electric locomotives are designed for the *average* work to be done, steam locomotives for the *maximum* work, since an electric locomotive designed for the average work will under all conditions easily be able to handle the maximum work. The use of the electric locomotive then makes it unnecessary to consider the ruling grade as a limiting feature to the capacity of the locomotive, whereas it must always be the limiting feature to the capacity of a steam locomotive. An illustration may make this clearer.

The six-axle Mallet compound locomotive used by one of the railways will pull, on the mountain division, having a grade of 2.2 per cent., an average of about 800 tons at a speed of 8.5 miles per hour, delivering therefore about 1,200 horse power at

the driving wheel. The locomotive weighs 250 tons with tender; the output is equal to 4.8 horse power per ton total weight. An electric locomotive weighing 100 tons, all on the drivers, will haul the same load up the same grade at 15 miles per hour and will develop approximately 1,800 horse power, equal to 18 horse power per ton. In other words, the power developed per ton on drivers in the electric locomotive is four times as great as in the steam locomotive.

Moreover, an electric locomotive could easily be designed to exert the same draw-bar pull at a speed of 20 to 25 miles per hour, and have no greater weight, than for 15 miles per hour. This Mallet locomotive will pull a load of only 530 tons up the grade at a speed of 15 miles per hour, using Mr. Armstrong's curves as a basis. The comparison on a basis of 15 miles per hour is then:

MALLET.

Engine and tender.....	250 tons
Train.....	330 tons
Total	580 tons

ELECTRIC

Engine.....	100 tons
Train.....	800 tons
Total....	900 tons

or the useful load at this speed is 2.4 times as great. This is merely another way of saying that steam service is incapable of handling heavy loads at high speeds.

The great advantage of the electric locomotive is, therefore, in the much higher speed possible. There is no inherent reason why a freight train should run at a lower speed than a passenger train; they do run at lower speeds simply because locomotives can not be built to haul them at the higher speeds, but the electric locomotive will probably change this and the speed of the freight service will be increased very greatly.

Another point should be noted in the above comparison. The steam locomotive weighs 150 tons more than the electric locomotive; assuming a duty of 100 miles per day, there are 15,000 ton-miles daily dead haul, which at the rate of 2 mills per ton mile amounts to about \$30 per day, or say \$10,000 per year. This is a clear saving in favor of electric locomotives. It can also be viewed as permitting an increase of 150 tons in the possible train load, and from this point of view the net earnings of an electric locomotive would be greater than that of a steam locomotive by the 150 tons extra load.

Something has been said by Mr. Armstrong about three-phase locomotives. I have recently decided to use the three-phase locomotives for the Cascade Mountain grade of the Great

Northern Railway, and among the reasons leading to this decision was the fact that the locomotive would have a fixed speed and could not be operated at a greater speed on the down grade. This equipment is for the freight service of the road only, at a place where much trouble has been caused by trains running away on the down grades.

Another reason leading to this decision was the recuperation on the down grade; this is valuable, not so much in the saving of energy, for in this case the additional energy, being supplied from a water power plant, would cost nothing, as in lessening considerably the capacity of power house required for any particular service. Two tons going down the grade will pull one ton up the grade; it is therefore necessary only to supply power for the tonnage up grade in excess of the down grade tonnage; with a system of train dispatching having this in view, a material saving can be made.

W. S. Murray: Law or economy brings electrification of railroads. It is peculiarly interesting, too, to note how economy hugs up to law, if law has been the cause. After law has had its turn, then comes the turn of the engineer. Such conditions may be levied by the law as to make impossible the operation of a certain piece of railroad mileage as economically by electricity as by steam. It is the duty of the electrical engineer to choose such a system consistent with safety and the guarantee of continuity of service, which will increase to a minimum amount the original operating expense. When economy dictates the electrification, again it is the duty of the electrical engineer to elect a system consistent with safety and continuity of service, which will decrease to a maximum extent the original operating expense.

The closing sentence of Mr. Armstrong's paper is:

The keynote of electrification is capacity; by approaching the problem from this standpoint only can full benefits be obtained.

I am in full agreement with Mr. Armstrong on this score, except I feel that while he has furnished the horse, there has been no mention of the carriage and what the carriage contains; in short, I should have said the keynote of electrification is "ton-miles", then capacity to handle it. The track capacity of a railroad is tremendously enhanced by electrification, but ton-miles must be on hand to make necessary the increased locomotive capacity.

I cannot escape a decided exception to Mr. Armstrong's reference, "Petty economies effected in coal consumption and cost of locomotive repairs". Examining the principal heads under operating expense, we find "maintenance of way and structures", "maintenance of equipment", "conducting transportation" and "general expenses". There is little choice in this list that electrification can detach upon which to practise its economies other than fuel and locomotive repairs. Of course the inference concerning the general increase of track capacity and operating fa-

cility, together with the fact that electrified lines offer more inducement for traffic in general, is not lost, but I cannot withhold figures that have come within my personal observation and keeping, which have a value keenly *important* rather than "petty" and, indeed, point directly to and are a demonstration of the keynote to electrification; namely, ton-miles.

In a previous contribution to the Institute's TRANSACTIONS in connection with the Stillwell-Putnam paper on the substitution of the electric motor for the steam locomotive, I presented figures that were worked out in a faithful effort by all concerned in it to secure what could be absolutely relied upon as the resistance of the main line of the New York, New Haven & Hartford Railroad Company between New Haven and Woodlawn. I shall briefly say in regard to this work, that after days of careful indication of steam locomotives on east-and west-bound runs with trains of varying weight for express and local-express service, the resistance for these several conditions was obtained, and the real relations between the ton-mile, the pounds of coal per ton-mile, and the horse-power-hours per ton-mile, were established in figures, upon which has been based the power house capacity necessary to operate the electric trains of the New Haven road. This effort was made to secure the actual service conditions rather than to depend on hypothetical resistance curves, the opinions on which are conspicuous for their wideness of variation.

Generating, transmission line, and railway equipment efficiencies are too well known not to be able, having determined the rim horse power required for propelling trains, to figure back to the power house the amount of the kilowatt capacity required to operate a predetermined schedule of trains. We cannot afford to quarrel with the machine efficiency of the steam locomotive. It is the equal of the machine efficiency of the electric motor morning, noon, and night. We shall take issue, however, on the efficiency which lies behind the two engines, viz: the generation of steam in the boiler of the locomotive versus its generation at the power station with its attendant transmission and conversion into electricity for application to the motors driving the locomotive.

The following table shows the saving of fuel which will be effected on the New York division when all freight and passenger trains, now operated by steam, receive their draw-bar pull by the electric method of traction.

	Ton-miles per annum	Tons of coal steam traction	Tons of coal electric traction	Cost of coal steam traction	Cost of coal electric traction	Saving of electric over steam traction
Express.....	592,240,000	57,447	29,870	\$183,830	\$89,620	\$94,210
Local-express.....	348,000,000	58,300	28,600	186,560	85,800	100,760
Freight.....	2,223,000,000	187,844	139,010	563,530	417,030	146,500
	3,163,240,000					\$341,470

In connection with the work done in the field to secure the data as compiled in the table just read, a diagrammatic tabulation of the observations considered pertinent to the test was made,

SHOWING	{	Average cut-off variation
		Boiler pressure variation
		Water consumption
		Indicated horse power
		Grade profile.

Ten locomotives were included in this test, and eighteen days of consecutive observation of performance were utilized.

Briefly, this diagram indicates that in express work 2055 indicated horse-power-hours are developed in the evaporation of 57,594 pounds of water, giving an average, therefore, of 28 pounds of water per indicated horse-power-hour; and on local trains this figure is slightly increased, the evaporation being 42,987 pounds of water for 1435 horse-power-hours, making the rate, 30 pounds of water per indicated horse-power-hour. I mention these figures, as we are all familiar with the turbine guarantees of 20 pounds of water, including auxiliaries, per kilowatt-hour at the switchboard which, reduced to a horse power basis, would be 15 pounds of water as measured at the switchboard. Remembering the ratio of 7 to 10 in the evaporation of locomotive vs. stationary boilers per pound of coal, it is not a stretch of conscience to concede that twice the draw-bar pull can be developed by the electric method of traction for coal burned under the boilers of stationary plants vs. coal burned in the fire-boxes of locomotives.

In that contribution, I also submitted figures bearing on the cost of repairs and maintenance of 20 steam, freight, and passenger locomotives; these have been kept most carefully over a period of one year and show 8.1 cents per locomotive-mile for freight engines and 5.6 cents per locomotive-mile for passenger engines. The engine mileage of the New York division of the New Haven road amounts to about 4,836,992 miles. This mileage is divided for passenger and freight service into 2,993,328 and 1,843,664 miles, respectively. These figures were based on week ending October 25, 1907, and it is to be noted that it will, therefore, be below the average, on account of the summer months bringing the heaviest traffic. This means an operating cost of \$316,962.00 per annum, for the maintenance and repairing of engines.

The average figures that I have been able to secure on electric engine repairs per locomotive-mile are about 2 cents. Increasing this figure 25 per cent. for safety and assuming the same number of electric engines replacing steam locomotives, (as a matter of fact there would be less electric engines required on account of the greater mileage per diem derived from electric locomotives) the total would be \$120,924.00 per annum, showing a saving over steam locomotives of \$196,038.00. Therefore, the net

saving on fuel and locomotive repairs in favor of electrification gives a round sum of \$562,470.00 per annum. This, upon a capital basis with money at 5 per cent represents \$11,249,400.00, a rather effective credit on the expense necessary to invest.

Messrs. Stillwell and Putnam's exhaustive and comprehensive analysis of the statistics of railroads for 1904, compiled by the Interstate Commerce Commission, and proof sheets of the report of the Commission for the year 1905, give the undeniable records of railroads of this country; and the averages for over five years, as shown in the paper read by them before this Institute, show fairly and honestly, where and where not economies may be effected. Of the four principal headings of operating expense as mentioned before, two of them, viz.: "maintenance of way and structures" and "general expenses" may be equated. Of the remaining two, viz.: the "maintenance of equipment" and the "conducting of transportation," the first of these indicates that operation could be effected by electricity at an expense of about 63 per cent. of that of steam; and of the 37 per cent. saved, 75 per cent. of this is on account of the economies in the repairs of electric vs. steam locomotives. Our steam experience, to date, enables me to confirm these figures of Messrs. Stillwell and Putnam.

Concerning the second item, viz: the conducting of transportation, which is generally the largest item in the operating expense of any railroad, it is to be noted that the estimated cost of operation by electricity is 79 per cent. of that of steam; and it is safe to consider that of the 21 per cent. saved, 90 per cent. of this is on account of fuel and round-house expenses. These figures are confirmed by the practical investigation which I have been conducting in an effort to secure the relative operating costs of the New York Division by electricity vs. steam.

Mr. Armstrong's paper is full of a most interesting line of initiative, and is particularly attractive to me on account of the broad scope in which he has handled this subject. The matter of fuel and locomotive repairs, has been one of such interest to me that I must ask the indulgence of the Institute in having dwelt with such length on these two details, from a paper which has covered so much other ground.

I may say that I almost regret to see the disappearance of the steam locomotive from the electric zone of the New York, New Haven & Hartford Railroad, as contrasts in operation are never better seen than when they are almost inseparately attached to each other.

In closing, I would refer to two details in operation, which unquestionably increase the capacity of a given trackage for trains operated by electricity, viz: yard switching, and turning of engines at terminals. I believe it is safe to say that our experience, to date, has demonstrated that in the first instance double the amount can be accomplished in the same time; and in the latter, electric engines are ready to make their reverse

train movement in 25 per cent. of the time required by steam locomotives, assuming that the water-tanks, ash-dumps and turntables, are within the yard limits of the terminal.

Wm. McClellan: We shall not be able to state positively what basis there is for electrification on the score of reduction in operating charges until we have a complete engine stage equipped electrically, with no steam locomotive shops, no steam repairs, no unnecessary buildings, but everything equipped to handle electrical equipment only, in the most economical manner. For this reason I think that the speaker of the evening has taken the proper view, when he bases his whole argument on capacity. He believes that heavy grades will prove the most fruitful field in which to start, and we must agree with him very heartily. It cannot be gainsaid that he has proved his case so far as this point is concerned in this paper. It should not be forgotten that all electrification to date has included a very great change in operating conditions and frequency of train service. As a result, electrification has been charged with many expenses which properly belong to amplification of the service and not to electrification proper. To get a just comparison in such cases it would be better to estimate what it would cost to give the increased service, both in quantity and quality, by steam locomotives, and compare this with the estimate required to do the same work by electric locomotives. In most cases I believe it would present the case for electrification in a much more favorable light than the way it is usually done.

I must also agree with the author that the electrification problem is not a substitution problem. It involves taking the traffic problem of the railroad and solving it along wholly different lines, from wholly different points of view. An electric locomotive is not something that is designed to replace a steam locomotive taken off rails. It has different capabilities, different possibilities, and these must be considered as influencing the whole traffic problem. The very greatest stress should be laid on this point in discussing the matter with our steam locomotive friends.

C. L. de Muralt: My belief is that, when one or two of the large railroads have been electrified, we shall find economies in operation to have slipped in, with or without intention. But the largest electrification work in the near future will likely be done for the reason that very much more traffic can be handled over existing tracks with electric locomotives than with steam locomotives. My office has recently had occasion to work out a problem where a road with something like eighty miles of double track was actually nearing the end of its ability to handle traffic with steam locomotives. The question came up of adding new tracks to increase its capacity. In this case, there would have been two additional tracks which would have cost something like \$15,000,000. On the other hand, a complete electric equipment for the old tracks, comprising power stations, dis-

tributing system, and locomotives, will cost only about \$3,000,000. The handling of the present amount of traffic by electricity will save in operating expenses something like \$200,000 out of \$800,000 and with the electric equipment pushed a little harder, there will be a chance to increase traffic forty to fifty per cent. over what the tracks will stand under steam. Here, therefore, is a case where electricity should be used and electric equipment installed just as soon as the \$3,000,000 can be raised.

Mr. Armstrong has not only reaffirmed that increase in capacity is the keynote, he has also shown us what he understands by capacity and what we should all understand by that term. It is a pity that so many engineers, who have to draw comparisons between electric and steam locomotives, are not quite clear on this point, and that comparisons have been made which are really quite a little misleading. It is not so much the tractive effort or the draw-bar pull which a locomotive can give, but the speed at which that draw-bar pull can be developed, which is important. And that is what Mr. Armstrong so nicely points out, when he defines as capacity, not merely draw-bar pull, but the product of draw-bar pull times speed. From this viewpoint Dr. Hutchinson's statement will look different. If I understand him correctly, he believes that steam locomotives could give about 9000 lb. draw-bar pull per axle, while no electric locomotive could be built to do the same. Personally, I am absolutely convinced that electric locomotives can do better than that. But, even if an electric locomotive could give only 4000 or 5000 lb. draw-bar pull per axle, but can carry that 4000 or 5000 lb. up to three or four times the speed at which the steam locomotive can develop 9000 lb. draw-bar pull, cannot the electric locomotive handle more traffic? In other words, is not its actual capacity much larger than that of the steam locomotive? As an illustration I have in mind a high-speed steam locomotive of the New York Central Atlantic type, which weighs about 160 tons, and develops a tractive effort at 45 miles per hour of about 13,000 lb., while the New York Central continuous-current locomotive weighs about 95 tons, and will carry at the same speed of 45 miles an hour a tractive effort of about 14,000 lb. In the one case about 80 lb. per ton, and in the other about 150. A European type of three-phase electric locomotive weighs about 70 tons and will carry at 45 miles an hour about 23,000 lb. of tractive effort, which is a still better showing. In short, I believe the question raised by Mr. Armstrong, and the solution offered by him, both show clearly what we are likely to come to: those lines will probably first be electrified which, with steam as motive power, are now at the limit of their traffic capacity. Electricity will show that for a comparatively small expenditure of money we can increase the traffic of such lines considerably, and I think we may look to an early use of electric locomotives for such purposes. That type of electric locomotive will in the end

prove to be the most useful, which in a given unit weight is able to concentrate the greatest amount of tractive power.

W. N. Smith: There is very little to add to what may be called the statistical feature of Mr. Armstrong's paper. He has had exceptional opportunity to go into such parts of the relative costs as are covered by the scope of his paper. But the problem is so complicated that the part of it which has here been covered in some detail does not cover the whole question. I agree fully with those who have remarked that the items which he has called petty or incidental are of considerable importance. They depend, of course, on the conditions of the particular road which the engineer may be called upon to investigate. A mountain road, or a road with a continuous long pull of 20 or 30 miles up-grade, is a different condition from a broken profile, or a level profile, such as the road from which Mr. Murray has given some figures. It is a very interesting proposition to consider the total resistance to be overcome in drawing a train over a line, and it is a relatively easy matter to consider it from that standpoint when the road is almost absolutely level; but when a large amount of drifting comes into play, with long down-grades, or with a broken profile, the problem becomes somewhat more complicated. It is very true that the whole question focuses upon capacity; but there are several different ways of looking at capacity, and one of the aspects that has not to my knowledge been given very much consideration in most of the communications on the subject, is the *capacity for train movement* of any given piece of single-track railroad. This is really a deep question. It is one that railroad operating men are daily in contact with, and it is to them that any question of capacity must appeal first. They are the men whom, first of all, you have to convince that you can increase the capacity of a piece of track, and while the possibilities of double track, as to increase, are considerable, the possibilities of single track are considerably less, particularly if the profile is undulating and operating conditions generally are difficult. It is quite conceivable that it would be found impracticable to get as many trains over a given piece of single track as would be required to make it a financial object to electrify that particular section. In such a case, of course, electrification would be reduced to an absurdity.

I mention this simply as a possibility. I have not had opportunity to examine a particular instance of this type carefully enough to define where it would begin to be an absurdity, but I know that such a consideration is apt to be present, and cannot be left out of the calculation. The operating man's standpoint is of the greatest importance, and it is one, I fear, to which many electrical engineers have not hitherto given sufficient consideration. The general trunk line electrification work of the future, however, must be considered from that standpoint.

I suppose that considerably more than 75 per cent. of the

mileage of the railroads of the United States is single track, and the cost of increasing the capacity of these roads by double tracking them, in order to enable a much greater number of trains to be run over the road in both directions, would stagger the imagination if it were estimated. Electrification is in some respects a simpler proposition to estimate on, in so far as cost is concerned, but there is no use trying to figure out how to run more trains over a piece of road than the road will accommodate. The questions of block signaling, turn-outs, and train-dispatching must enter into the problem first of all.

The capacity of the steam locomotive has been mentioned as being in some instances greater than could possibly be obtained continuously from an electric locomotive, but it occurs to me that this will depend to some extent on the conditions under which the steam locomotive is to operate. We know that up-grades of 30 miles or longer actually exist where a steam locomotive working at full power has to stop for water on the way up; of course it can go right along again at its maximum capacity after it has filled its tender, but when it has worked up to the point where all its water is exhausted, the locomotive must stop to have the supply replenished; and to that extent there must be some qualification to statements regarding the uniformly high capacity of a steam locomotive.

The question of load-factor has not been touched upon in the discussion of the cost of power. I will not undertake to discuss it, except to state that it seems to me rather an important matter to consider in making an estimate of what the cost of power will be in predicting the economic performance of an electrified section. Of course it goes without saying if the section is congested the load-factor will be high, but if the trains are few it will not be high and the cost per kilowatt will run up.

The weight of the tender has been mentioned, and any one who will examine the general data of the heaviest steam locomotives now being turned out will perhaps be somewhat surprised at the enormous weight of the tender, a dead weight, which, though a part of the motive power, cannot produce any tractive effort.

It is probable that a comparison with the consolidation type of steam locomotive will show a greater economy for electric power than will a comparison with the Mallet type of locomotive, which is said to be very successful in mountain work.

The various items of cost, even those called "petty", which enter into locomotive operation and maintenance, whether steam or electrical, are so variable that differences of a comparatively small number of cents per locomotive mile in a few items may make a large difference in the showing that the final tabulation will produce, and may throw the balance one way or the other, and every possible item of expense must be taken into consideration in making a comparison that will pass as valid when presented to the practical railroad operating man.

Chas. P. Steinmetz: The leading conclusion of Mr. Armstrong's

paper seems to be that the advantage resulting from electrification is to be found in the increased capacity; that is, the ability of the road with the same trackage to handle a greater amount of traffic. This, however, means that the change from steam power to electric power is not a mere substitution of the electric locomotive for the steam locomotive, but a readjustment of the ways of operation; that is, an increase of the speed of operation of freight service by taking advantage of the feature of the electric locomotive to be able to carry its draw-bar pull up to a higher speed. We usually find, when introducing a more advanced way of doing a thing, that we have not a mere substitution, but to get the greatest benefit from the change, the method of operation must be rearranged. Nearly a century ago when the stage coach was replaced by the steam engine, the first attempts to attach the steam engine to the stage coach and pull it over the country roads came to naught, and steam propulsion became successful only by putting the locomotive on the railway track. A characteristic of the steam locomotive is that it is essentially a constant power motor. It gives approximately the same power whether running at high or low speed. The draw-bar pull, therefore, does not tell the whole story, but the limit is the steaming capacity of the boiler, and the faster you move the oftener you fill the cylinders, and since you cannot for a long time exceed the ability of the boiler to produce steam, you have to cut off earlier, and so get less draw-bar pull. Not so in the electric motor; in this the limitation essentially consists in the constant loss of power. The limit of the electric locomotive is that it must lose only so much power in the motor, in the general average, as to be within safe heating limits. Since efficiency rapidly increases with the speed, it means you can get more power out of it at higher speeds, up to a certain limit, and therefore the electric locomotive is best at higher speeds than the steam locomotive, and we have to take advantage of this feature if we desire to show the best results. It, therefore, as you see, does not mean a mere substitution, but also means a readjustment especially of the most important part of the railway service, the freight traffic, for higher speed. Higher speeds necessarily mean increased capacity of the system, even without any increased draw-bar pull, even with less draw-bar pull, and in this feature I believe lies the main advantage of electric traction; but it makes it necessary to readjust the method of operation to the changed condition of railroad motive power, to get the best results of the electric locomotive. You may merely substitute, but you get better results by not merely substituting, but also by increasing the speed to operate at the most economical speed of the electric locomotive, and this in general is higher than the most economical speed of the steam locomotive.

A. H. Armstrong: In working up the comparison of the performance of the steam and electric locomotive I was impressed with the

fact that the greatest benefit to be secured seemed to lie in the electrification of mountain-grade divisions. That is, the greatest necessity for electrification as well as the greatest return for the money invested are met with on heavy grades, and I am, therefore, very much pleased to find that the economy figures given by Mr. Wilgus as obtained in actual service on the New York Central check up in some degree the final results I have arrived at by calculation. Also that the calculated figures by Mr. Murray for another section of a level road, New York, New Haven & Hartford Railroad, indicate a comfortable return upon the capital required for electrifying the New York division of that road. With these figures for level operation it would seem as if my general conclusions for the electric operation of mountain-grade divisions were very conservatively arrived at.

In regard to the remarks of Dr. Hutchinson, that a total draw-bar pull or tractive effort of 9000 pounds could not be continuously sustained by an electric locomotive, I have only to point out two or three facts of operation which may perhaps have been overlooked by him in making the statement. With 50,000 pounds per axle and a tractive effort of 20 per cent., which is conservative for average conditons of track, 10,000 pounds of tractive effort is available. In practice, however, it is not possible to work any locomotive at this tractive effort continuously irrespective of its type of motive power, owing to the broken character of all profiles, as even on mountain-grade sections crossing a continental divide the grades are not uniform, but the average grade is seldom more than 60 per cent. of the maximum or ruling grade. For example, the greatest extent of continuous grade in this country is on the Sacramento Division of the Southern Pacific system, which has a 1.54 per cent. average grade for 83 miles with a ruling grade of 2.2 per cent. In other words, during the rise of 7000 feet in 83 miles the average grade is 70 per cent. of the ruling grade. A locomotive operating over this division will be called upon to sustain, say, 60 per cent. of its maximum tractive effort, thus leaving a margin of 10 per cent. over the demands of the ruling grade in order to start up the train on maximum load and grade conditions. Under these conditions the electric locomotive would not in any way suffer in comparison with the steam locomotive, as the heating of the motive power would not in any way prohibit the delivery of 6000 pounds per axle at any speed that may be safe in operation. Furthermore, it is necessary to take into account the very serious delays occurring on single-track roads where the traffic may be heavy; so that all operating conditions considered, I see no reason why it should not be possible to keep the temperature rise of the electric motive power well within safe limits in practice.

In choosing the word "petty" I seem to have been particularly fortunate in irritating Mr. Murray into giving some very valuable data pertaining to tests made by him on the

New York, New Haven & Hartford tracks with steam locomotives. Mr. Murray's figures are going to prove very interesting reading when we have a chance to go into them in detail at greater leisure, but I am surprised to see that such a low steam consumption (28 to 30 pounds per i.h.p. hour) was arrived at in actual tests. This steam consumption could be looked for by indicator, but it seems rather low if it includes all the stand-by losses of the locomotive not in actual operation.

In dealing with steam locomotive statistics I have found it necessary to divide the determination of coal and water consumption into two parts. First, that required for the actual hauling of the train; secondly, that lost while coasting or standing still. For instance, I show in the paper that on a certain road there are some 400 pounds of coal and 4000 pounds of steam used per hour while locomotives are idle at terminals, turn-outs, or coasting down grades, while the performance of this simple consolidation engine when actually hauling a train corresponded to a steam consumption of 28 to 30 pounds per boiler horse-power-hour with an evaporation of approximately six pounds of water per pound of coal. The Mallet Compound requires more coal than this chargeable to stand-by losses, and further requires the admission of steam in order to coast down grade at a speed much higher than 10 or 12 miles an hour. All of these losses in steam locomotive operation amount up to a grand total that in many cases will show a considerable excess cost over the cost of electric power for hauling the same tonnage with electric locomotives. Hence my feeling that the figures submitted by Mr. Murray are somewhat low for the total coal and water consumption of the locomotive for twenty-four hours in regular service.

I must adhere to my position taken in the paper that economy of operation as regards coal consumption does not constitute any sufficient cause for electrification in the great majority of cases, and I think we cannot bring out this fact too strongly. It is not sufficient to show the management of steam roads that they can get a return of 10 per cent. or even 20 per cent. upon \$10,000,000 or more required for electrification, as they are not looking for investments of this character. Careful consideration, however, will be given to any report showing means of increasing gross receipts or that will offer a reliable substitute for the double tracking that may be necessary to provide for a rapidly increasing tonnage. I must adhere, therefore, to the idea that the main reason for electrification of roads other than terminals, tunnels, etc., is embodied in the increased capacity of the electric locomotive, providing increased tonnage capacity of the tracks, decreased running time, etc.—all of which guarantee an increase in gross receipts and a possible saving in expenditure for additional tracks, reducing ruling grade, etc. That this electrification will be accompanied with a gratifying reduction in operating expenses is a still further argument for replacing the steam locomotive, but it is not of sufficient

importance in itself in the majority of cases, to encourage electrification.

I note the doubt expressed by Mr. Smith as to the saving effected in the electrification of single track roads, and would state that it is on just such roads as these where the greatest saving can be effected both in cost of electrification and in operating expense. A large volume of traffic is carried over a single-track road under the greatest difficulty and at considerable expense. This applies especially to trains hauled by steam locomotives which are capable of only six or seven miles per hour schedule speed up severe grades, and add considerably to the number of signal stops by reason of their limited radius of action with their coal and water supply. For instance, a steam locomotive working at an average of 75 per cent. of its full boiler capacity on a mountain grade cannot cover more than 15 to 20 miles without taking on more water, in this respect very much resembling the electric automobile forced to return frequently to its charging station for the material for a fresh start. It is entirely safe to say, therefore, that the total tonnage capacity of a single track will be very much increased with the adoption of the electric locomotive, and the cost of such electrification in some cases may be considerably less than the capital required to double track or duplicate the single track already installed. In other words, where a mountain-grade division has reached the maximum tonnage capacity possible with single track, and it becomes a question of double tracking with steam locomotives, a careful analysis of the conditions may show that electrification of the present single track may be accomplished with a lesser expenditure and be followed with a greater return upon the money invested.

I agree with Dr. Steinmetz in the views expressed by him and would draw the attention of the members to the entire revolution in methods of handling short-haul passenger traffic by the introduction of the electric motor. I believe also that the introduction of the electric locomotive will bring about fundamental changes in the method of handling freight traffic by reason of the many inherent advantages enjoyed by the electric locomotive and not shared by its steam competitor.

W. S. Murray (by letter): In answer to Mr. Armstrong's question as to whether the coal measurement was made for the full 24-hour day, including the hours during which the engine was not doing revenue work, such as time spent in the round-house, over ash-pits, cleaning fires, etc., I would say that this was the case; the idea not being simply to get the rate of coal per horse-power-hour while the engine was making its revenue runs, but to secure the real commercial rate or day consumption, which governs the bill the railroad company pays.
