DISCUSSION ON "TWO-MOTOR VS. FOUR-MOTOR EQUIPMENTS."

N. McD. CRAWFORD (by letter): I desire to explain more fully the term "A" in the efficiency formula given in my paper. The definition of the term, as given, may be misleading; its value is obtained by multiplying the average watt-hours per ton-mile by tons weight of car, and this result by the cost of power per watt-hour at the switchboard.

I have named the efficiency obtained "commercial efficiency." It has been suggested that possibly "load factor" or "earning efficiency" would be better. But I have looked at the matter from the standpoint of the street railway manager rather than from that of the engineer.

A. H. ARMSTRONG: The contest between two- and four-motor equipments is of long standing, but of late years it seems to have settled itself rather definitely in a majority of cases in favor of the four-motor equipment. As Mr. Crawford brought out in his paper, no general ruling will apply in all cases, and each traction problem will have to be solved according to the local conditions. Perhaps the fundamental reason for adopting the four-motor equipment is the need felt for increased traction, due partly to climatic conditions in the north, partly to the presence of excessive grades on many roads, and partly in some cases to an exacting schedule, calling for a more rapid rate of acceleration than can be obtained by a two-motor equipment. In the latter class of roads may be included surface lines in cities of considerable size. On elevated, subway, or other city roads on which the surface condition of the rails is particularly good, the adoption of two-motor equipment is permissible so far as the question of traction is concerned, and this practically constitutes the legitimate field of the two-motor equipment.

In suburban and interurban service somewhat different conditions apply, cars are usually run singly at infrequent intervals; in many cases over excessive grades; because of the infrequency of the headway snow and ice accumulate, thus calling for as large a tractive effort as can be obtained even with four motors.

Referring to the paper, there are several assumptions made which perhaps can be looked at in a different way. In arriving at the efficiency of operation of the different cars cited, the author assumes that at the end of every mile an entirely new set of passengers is taken on board. Thus, if instead of a one-mile basis a two-mile basis had been taken, the 17% efficiency of operation noted in the case of car 169 would have been nearly doubled, without in any way changing the factors entering into the case. It would seem, therefore, that the method of the author is somewhat misleading, in that the commercial efficiencies obtained are arbitrary and do not necessarily represent the true prevailing conditions.

Again, on pages 69 and 70, the energy consumption of the two-motor equipment is given as somewhat less per car than that of the four-motor equipment. This brings up another point which has been the subject of discussion at previous meetings of the INSTITUTE; that is, the relative amount of energy consumed by two-motor and four-motor equipments. If one car is equipped with two motors, and a similar car is equipped with four motors, both cars having the same aggregate horse power capacity, there is no reason why the energy consumption in one case should be different from that in the other, provided the car weights, schedules, frequency of stops, and general conditions, are similar in each case. The method of comparing two- and four-motor equipments adopted by the author is somewhat unfair, as the operation of two 35-h.p. motors is compared with that of four 35-h.p. motors placed upon a similar type of car; obviously, in one case the motors are overloaded; in the other they are underloaded. Of course the four-motor equipment will weigh more and the energy consumption will be increased on account of the increase in weight. It would have been fairer to compare the operation of two 75-h.p. motors with the operation of four 35-h.p. motors. The watt-hours per ton-mile assumed for any given service is practically independent of the subdivision of power on the car inasmuch as the railway motors of the same manufacturer are all designed along the same general lines and offer about the same efficiency curve as expressed in per cent. at full load.

Perhaps one reason why results given by the author are more favorable to two motors than to four motors is that an insufficient number of tests has been taken. The average of a large number of tests is necessary in order to arrive at a correct understanding of the operation of a car under any given conditions. There is no reason why, with the conditions in the two cases the same, the four-motor equipment should not show as small, if not a smaller, energy consumption per ton-mile than the two-motor equipment.

S. T. DODD: In attempting to express the commercial value of different cars, the author has included both their operating expense and seated-load value in one term which he has called "commercial efficiency." Apparently it would have been clearer to have separated this term into two different expressions. I have tried to indicate my idea of this method of expression in a table, in which the items of "interest" and "platform labor" are taken directly from the values given on page 67. The expense of car repairs should be included, and in the absence of more definite data, this is assumed as 1.5c. per car-mile. The author's method, on page 67, of getting at the expression for cost of power per car-mile hardly seems correct, but it will not be far from the truth to assume the cost of power to be 1c. per kilowatt-hour delivered at the car, and take the amount of power for the several cars from Figs.

3-6. Adding the terms together gives an expression for operating expense per car-mile which indicates that car No. 169 is the most economical in operation. Going one step further and dividing the expression by the seating capacity of each car, gives the operating expense per seat-mile, which indicates that car No. 480 is the most economical.

Car No.....	169	183	101	480
Platform labor.....	0.0475	0.0475	0.0475	0.0475
Interest and depreciation.....	0.0043	0.0056	0.0070	0.0087
Car repairs.....	0.0150	0.0150	0.0150	0.0150
Power.....	0.0069	0.0140	0.0180	0.0175
Operating expenses per car-mile	0.0737	0.0821	0.0875	0.0887
Operating expenses per seat mile	0.00368	0.00241	0.00257	0.00211
Seat factor.....	$\frac{0.23 \times 5.25}{1.30}$	$\frac{0.23 \times 5.25}{1.70}$	$\frac{0.22 \times 5.25}{1.70}$	$\frac{0.23 \times 5.25}{2.10}$
	= 93%	= 71%	= 68%	= 57.5%

This method of discussing the question shows that if the seating capacity of car 169 is sufficient to accommodate the travel, this car is the one to use; but that if it has not sufficient capacity, then car 480 is the one most advisable to use because of its low operating expense per seat-mile.

Now if in addition to this information it is desired to introduce an expression indicating the amount of idle seating room in each type of car, this may be expressed by a separate ratio, which I have called "seat factor," and which is obtained by dividing the earnings per trip by the "value of the seated load." This expression I have also given in the table.

I have assumed 1.5c. per car-mile for repairs, but very little information on car repairs is available for determining the respective cost of repairs of large and small equipments. It appears from the table above that an increase in car repairs of 1.5c. per car-mile, on car 169 over car 480 for example, would make a four-motor equipment more economical from the standpoint of operation per car-mile, as well as from the standpoint for operation per motor-mile.

A claim that is often made for the superiority of the four-motor equipment over the two-motor equipment of the same aggregate capacity is that the four-motor equipment having a greater radiating service will run at a cooler temperature than the two-motor equipment when working under the same load. But comparative tests which I have made upon stationary motors indicate that the average four-motor equipment should operate at the same temperature as a two-motor equipment of the same aggregate capacity.

Turning to the appendix to the paper, it will be seen that the differences of temperature do not correspond to the difference between two-motor and four-motor equipments, but that cars 138 and 101 are running at temperatures in the

neighborhood of 70°, while cars 480 and 169 are running at temperatures in the neighborhood of 30°. The cause of this difference in temperature is indicated in Figs. 2-6, inclusive, which show the large amount of power per car-mile used by the cars 138 and 101; while Fig. 2 in particular shows that the maximum peaks of power taken by car 138 (a 12-ton car with two-motor equipment) are equal to the maximum peaks taken by car 480 (a 20-ton car with four-motor equipment). Apparently the difference there indicated is due to the difference in gearing between the two equipments; and the differences in temperature shown in the appendix indicate very clearly that the two cars in question were geared for a speed too high for economical operation upon the schedule and for number of stops required.

CALVERT TOWNLEY: Frequent comparisons between two-motor equipments and four-motor equipments have been made, and these comparisons are nearly always clouded by the introduction of other factors; for example, the question of the size of car to use, a question to be determined by the density of traffic and other local conditions. After the size of the car best suited for local conditions is selected, the number of motors to be used should be taken up as an entirely separate question. Similarly, within ordinary limits, any reasonable gear ratio can be applied to either form of equipment so that gearing should be eliminated from the comparison.

Mr. Crawford's comparison of the watt-hours per ton-mile shows the most economical motors to be those having the greatest gear reduction, as will always be the case for city service with low schedule speed and frequent stops. The comparison of a two-motor equipment with a four-motor equipment of a greater aggregate horse power capacity is unsatisfactory; to get an absolutely fair comparison, the same horse power per ton of weight carried should apply to both styles of equipment. A four-motor equipment would be somewhat heavier than a two-motor equipment having the same capacity and, therefore, if the horse power per ton were kept equal, the total weight of a car equipped with four motors will be greater than of one of equal capacity equipped with two motors. Additional energy to propel this car would be required at least in proportion to the additional weight. In a similar manner, the first cost of the four-motor equipment will be somewhat greater. Further, there is an increased maintenance to be charged against the four-motor equipment because, as is well known, repair-shop facilities must be provided for a given number of units, and a larger shop, with a greater number of men, is required to take care of twice the number of motors, with twice as many wearing parts, etc., to be maintained.

Summarizing, therefore, there should be charged against the

four-motor equipment an increased first cost, an increased consumption of energy due to increased weight, increased number of bearings, pinions, gears, etc., and an increased cost of maintenance. Admitting this, what is the reason for the tendency toward the substitution of four-motor equipments that is noticeable in the practice of to-day? The answer always is: because four-motor equipments afford increased traction.

The speaker excludes from the comparison, cars of such great weight or high speed that sufficient motor capacity in a two-motor equipment can not be provided, and limits the comparison to cases where either arrangement will be available. With the two-motor equipment, there will be from 55% to 60% of the total weight of the cars on the drivers. Under the best conditions of rail, straight track, etc., 20% adhesion is easily obtainable. With 60% on the drivers, there are 1200 pounds on the drivers for every ton weight of the car, and 20% of this is 240 pounds. Therefore, there is available with a two-motor equipment, under good conditions of track, 240 pounds tractive effort per ton. On a very heavy grade, say 8%, 160 pounds per ton will be required to lift the car up this grade, and if 20 pounds be allowed to overcome friction (an allowance rather higher than usual), there will still remain 60 pounds per ton for acceleration, which will give a very satisfactory performance. This brief consideration of the problem shows that even for very heavy grades, with fairly good track conditions, there is ample adhesion with two-motor equipments to get the necessary acceleration.

On the other hand, with snow and slush on the rail, there may be at times practically no adhesion from one truck, so that the 1200 pounds per ton is reduced to 600 pounds, and with an icy rail, instead of 20% of adhesion, only 10%, or even less, may be available. Ten per cent. of 600 pounds is 60 pounds, and with a slight grade and heavy snow in front of the wheels this amount is at times insufficient to start the car. These conditions, therefore, demand a four-motor equipment.

Engineers should not be carried away by fashion and adopt a four-motor equipment because others do so, or simply because such equipment afforded better traction, unless a careful study of the local conditions shows that such traction is necessary for the service.