INCREASING CAR OPERATION ECONOMIES

A Dollar Saved in Operating Expense is *One Hundred Cents* in Net Earnings

INCREASING CAR OPERATION ECONOMIES

PRINTED BY
FEDERAL PRINTING COMPANY,
NEW YORK

INCREASING CAR OPERATION ECONOMIES

BY

C. C. CHAPPELLE

CONSULTING ENGINEER AND VICE-PRESIDENT
RAILWAY IMPROVEMENT COMPANY

[LIMITED EDITION]

1916
RAILWAY IMPROVEMENT COMPANY
NEW YORK

Foreword

THIS volume has been prepared to assist those interested in the problem of securing better economies in the practical operation of electric railway cars.

Financiers, executives, men actually directing operations, and everyone interested in increasing the economies and net earnings of electric railways will find presented information and practical suggestions worthy of the most careful consideration.

The principles controlling and determining the possible economies and limitations for standards of service are discussed; as, also, the methods commercially available for securing the obtainable results in practice. Our impelling motive is the belief that a thorough understanding of such principles will be the deciding basis for a decision as to the effective method for securing the available results.

This brings us to the point that the Rico Coasting Recorder is not the embodiment of some new and wonderful principle in car operation, but an instrument that helps the motorman to attain in practice the motor efficiencies that the designer considered in the design of the equipment, as obtainable for the stated operating conditions.

Since the mechanical accuracy of the Rico Coasting Recorder is not in dispute, it remains to prove that the thing that the Recorder measures—coasting—is the correct measure of actual efficiency in the use of electrical energy. This proof is furnished conclusively in the study by Mr. Chappelle, herewith.

First of all, let it be clearly understood that Mr. Chappelle does not stand alone in stating that coasting is the correct measure of efficiency. On the contrary, every motor designer tacitly recognizes the truth of this statement by including a coasting period in determining the adaptability of the equipment for the stated operating conditions, based on the motor characteristic performance curves.

Mr. Chappelle, however, has gone further by pointing out in detail just what the correct utilization of coasting means in every-day practice. To this end he has made clear the fact that for any given set of operating conditions the resulting coasting shows the most efficient combination for the proper rate of acceleration, the proper rate of braking, the duration of stop, etc.

As these are all time-element factors, a time-measuring device, the Rico Coasting Recorder or the Rico C & S Recorder, is the logical instrument for checking them.

Perhaps the most valuable feature of Mr. Chappelle's study (in Chapter Two) is the relation which it establishes between power and platform costs, schedule speeds, and coasting, to the number of stops of traffic conditions. This relation shows when it is more profitable to save wages by decreasing coasting time than to save power and brake shoes by increasing coasting time.

While Mr. Chappelle's study (Chapter Two) demonstrates that coasting is the correct measure of efficiency, Chapter One discusses the types of devices, available commercially, for checking the efficiencies of power and other factors entering into car operation in practice, and more particularly the new Rico Coasting and Service Recorder (commercially abbreviated Rico C & S Recorder), which gives the number of stops, the time consumed for stops, the actual running time in which the schedule time is made, in addition to the coasting time and identification features of the original Rico Coasting Recorder. The Rico C & S Recorder card form record may also be used to compare the motorman's platform time with his pay-roll time which may be recorded on the same card record.

It would be hard to overestimate the wonderful possibilities of the Rico C & S Recorder in the hands of the practical railway operator. At last he has at his command an automatic analyst which can tell him, not once a year, once a month, once a week or once a day how the most important elements of operating cost are being affected, but a device that reveals what is going on from minute to minute!

Following the conclusion of Chapter Two are letters from a prominent engineer of each of the great electrical manufacturers, also, from Mr. H. St. Clair Putnam, one of the recognized authorities on railway engineering and operating practice, reprinted by permission, from the *Electric Railway Journal.*

Mr. W. B. Potter, Engineer, Railway and Traction Department, General Electric Company, says:

> "I quite agree with his (Mr. Chappelle's) argument in favor of the maximum percentage of coasting practicable as an effective method of minimizing the power required for a given run, and that a record of the percentage coasting is a desirable and effective means of determining the relative operating efficiency of different motormen."

Mr. Potter also cautions against attempting to secure the lowest power possible through using rates of acceleration and braking that would be hard on the passengers and on the equipment. With this caution we are in full agreement, but we would add that the Rico Coasting Recorder or the Rico C & S Recorder is the only device that directly reveals excessive rates of acceleration and braking. An energy recording device, obviously, cannot show that the desired rates of acceleration and braking (with corresponding coasting percentages) have been unduly exceeded.

Mr. F. E. Wynne, Engineer, Railway Section, General Engineering Division, Westinghouse Electric & Manufacturing Company, states:

> "Mr. Chappelle's discussion of these principles brings out a point which is frequently overlooked in practical operation; namely, that under a given set of conditions, the power input to the car is determined by what he designates as 'time-element factors.' "

Mr. Wynne also believes that:

> "A knowledge of the frequency and duration of stops is also necessary in order to satisfactorily analyze a service and determine from the analysis what schedules are most economical."

It is our pleasure to add that the new Rico C & S Recorder meets these various requirements.

Mr. Putnam makes several timely comments, among others, pointing out that the sub-section, "Series Operation," in his 1910 A. I. E. E. paper, had reference to "Pausing on the series position of the controller," and not to the operation of running on the series position of the controller, as some have inferred. Mr. Putnam also points out that both operations should be avoided for general efficiency, as equipment is selected for normal operation in multiple, series operation being a special contingency for certain features encountered in practical operation.

We can think of no stronger endorsement of the need for a device that measures and records the efficiency of the motormen than the article by Mr. J. F. Layng entitled, "Relation Between Car Operation and Energy Consumption." In this article, which we reprint (Chapter Three) through the courtesy of the *General Electric Review*, Mr. Layng says:

> "With the same car over the same route, with the same number and length of stops, the power consumption will vary more than 30 per cent when operated by different motormen."

Mr. Layng calls attention to the desirability for keeping records of the motorman's operations, as is done in the matter of other expenditures, and states:

> "By keeping these records and following them up properly, savings in power of 20 to 25 per cent can reasonably be expected."

It is the function of the Rico Coasting Recorder and the Rico C & S Recorder to bring the energy consumption of the motorman to the efficient minimum—and to keep it at such minimum.

We have (Chapter Four) reproduced, by permission, portions of Mr. F. E. Wynne's paper (read before Baltimore Section A. I. E. E.) entitled, "Economies in Railway Operation," without which a consideration of the subject of Efficiency would be incomplete.

In Chapter Five, Mr. Chappelle discusses "Car Operation Efficiency—With Special Reference to Energy-Input Method of Determining Motormen's Efficiency." To those who may prefer the meter method for checking efficiency, Chapter Five will be interesting reading.

To conclude: All authorities emphasize that most efficient management is impossible without a constant analysis of the operating results in connection with traffic conditions. Such analysis is effectively obtainable only with the Coasting Recorder equipments developed by this company and now in successful use under the widest conceivable range in electric railway operation.

RAILWAY IMPROVEMENT COMPANY.

NEW YORK, *April*, 1916.

INDEX

[Index continued on next page]

INDEX [*Continued*]

Chapter One

The Commercial Application of Fundamental Principles of Car Operation Efficiency

Chapter One

The Geometrical Arrangement of [illegible]
[illegible]

Chapter One

The Commercial Application of Fundamental Principles of Car Operation Efficiency

By C. C. CHAPPELLE

Consulting Engineer and Vice-President
Railway Improvement Company

EVERY electric railway company is confronted with the necessity of increased economies in operation. The competition of other means of transportation (particularly the pleasure automobile) tends to curtail the natural growth of gross earnings.

The constant upward trend of labor and material costs tend in connection with the almost universal fixed rate of fare to reduce net earnings.

Capital, vital for the maintenance and development of railway service, is turning to other and more attractive fields for investment.

In considering the means available for reducing operating expenses, the advantages and possibilities of improved designs and lighter weights in motor and car equipment are well known, as also one-man cars where conditions permit one-man operation.

The investment in present equipment is usually such that it is impracticable to write off the investment in existing equipment, advantageously, from the obtainable economies by means of new equipment.

Therefore, it is apparent that the logical and effective method for increasing net savings is by reduction in operating expenses through increased efficiency in the use of either old or new equipment.

Time Element Factors Control Efficiency

The fundamental principles involved in the attainment of efficiencies in car operation are analyzed and discussed in Chapter II hereof, but as many readers may be too occupied or not inclined to delve into a somewhat technical study, we summarize here the conclusions established from such analysis of the fundamental principles, as follows:

[I] The power input required to operate a given car and its equipment of given gear ratio, at a given average schedule speed, with a given average number of stops per mile and a given average trolley voltage is controlled solely by the following factors: The duration of acceleration, *i.e.*, the rate of acceleration; the duration of braking, *i.e.*, the rate of braking; and the duration of stops; all of which are time-element factors. The maximum power input and maximum speed attained occur with no coasting time. The power input and maximum attained speed both decrease as the duration of acceleration, braking or of stop, respectively, decrease. The increase in percent coasting is in proportion to the decrease per cent of power input. The ratio of such proportion approaches for general average conditions approximately one to one.

[II] The other given conditions of (I) remaining unchanged (utilizing the time-element factors of acceleration, braking and duration of stops on any selected basis), the maximum number of stops per mile is obtained with no coasting time, with resulting maximum power input and maximum attained speed. The power input and maximum attained speed both decrease, and the coasting time increases, as the number of stops per mile decreases. The important fact is demonstrated that the increase in percent coasting is in proportion to the decrease percent of power input. The ratio of this proportion approaches approximately the same one to one ratio as in (I) for the increase in percent coasting to the percent decrease in power, due to efficient utilization of the time-element factors, acceleration, braking and duration of stop.

[III] The other given conditions of (I) remaining unchanged (utilizing the time-element factors of acceleration, braking and duration of stops on any selected basis), the maximum schedule speed is obtained with no coasting time, and with maximum power input resulting. The power input decreases and the coasting time increases as the schedule speed decreases. The increase in percent coasting is in proportion to the decrease percent of power input; the ratio of this proportion approaching approximately the same one to one ratio as in (I) and (II).

[IV] As the maximum attainable speed is approached, for given conditions, the power input mounts in large increments. Hence a point is reached where the reduction in platform expense, due to increased schedule speed, is offset by the increase in power expense, dependent for given conditions upon the relative unit costs for platform and power expense. The relation of such unit costs, encountered in practice, is such that any schedule speed which is too high to result in possible coasting is an uneconomical schedule speed.

Coasting an Essential Factor in Economy

The fundamental principles, summarized in the preceding paragraphs (I) to (IV) inclusive, establish for given conditions and equipment of given gear ratio, that efficiency is solely dependent upon the efficient utilization of the controlling time-element factors; the efficient utilization of these time-element factors is measured by the coasting time and percent coasting for the varying conditions encountered in practical operations. For any schedule speed now in effect on any railway or for any adopted schedule speed, increase in coasting means increase in efficiency; and any schedule speed to be economical must be such as to permit possible coasting.

For a given car, with given equipment, there is a most economical schedule speed, dependent upon traffic conditions and the relative unit costs for power and platform expense. Such economical schedule speed has a corresponding resultant percent coasting. If the schedule speed approaches the economic schedule speed for the traffic conditions, the corresponding resultant percent coasting shows little variation over the ranges of traffic conditions usually encountered in practical operation.

Correct Method Efficiency Checking System

The fundamental principles of car operation efficiency, hereinbefore analyzed and discussed, establish that the measurement of the coasting time and the determination of the percent coasting therefrom is the correct relative measure of efficiency in practical car operation. The percent coasting is, therefore, the proper basis for a correct method efficiency checking system.

Rico Coasting Recorder

The Rico Coasting Recorder (Fig. 1-A) is essentially a clock mechanism of simple and rugged design, so constructed and connected, by suitable electric relay with the car wiring and brake equipment, as to measure and print the time during which the car is in motion with "power off" and "brakes off," or in other words, the coasting time. Therefore the Rico Coasting Recorder meets the requisites for a correct method efficiency checking system.

The Rico Coasting Recorder during the past five years has been so widely advertised by descriptive articles in the technical trade press on its varied and numerous installations on representative railway systems, that space will not be taken here to describe its details.

The Rico Coasting Recorder for each trip run gives the motorman a printed voucher slip (see Fig. 2-A) showing the car number, the motorman's number and the coasting time in minutes. Such voucher slip shows the motorman (and his executive) *how* and *when* he operates efficiently through his efficient utilization of the time-element factors which are the only factors under the motorman's control that can possibly affect the power input.

Rico Coasting Recorder

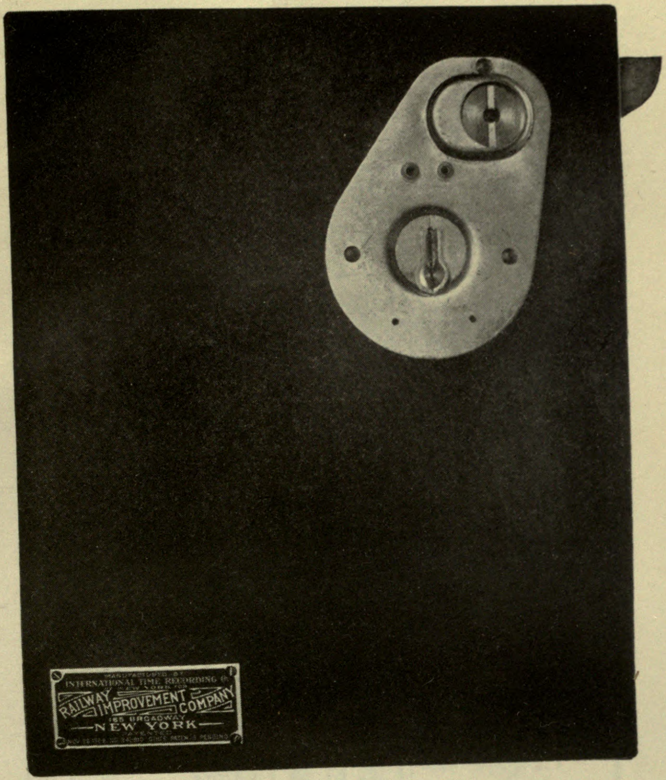


Figure 1-A
Rico Coasting Recorder

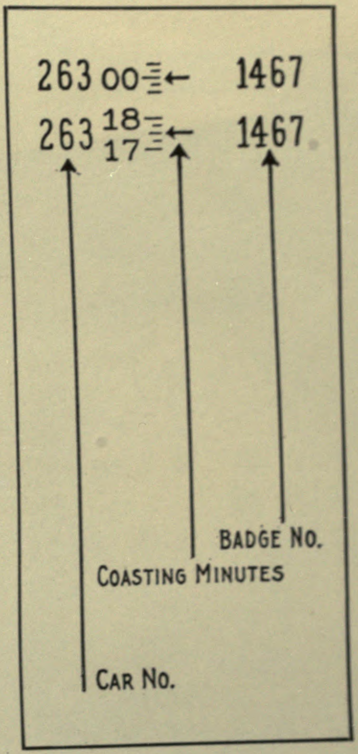
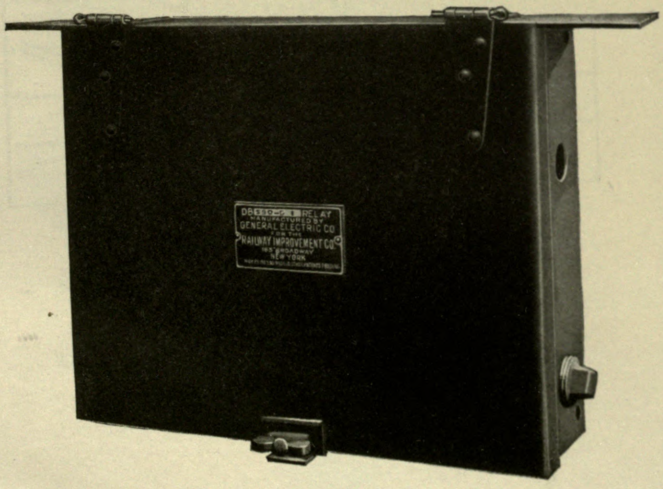
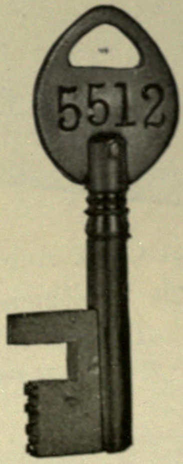


Figure 2-A
Voucher Slip



"RICO" Type No. DB590 Form G
Rico Coasting Recorder Relay

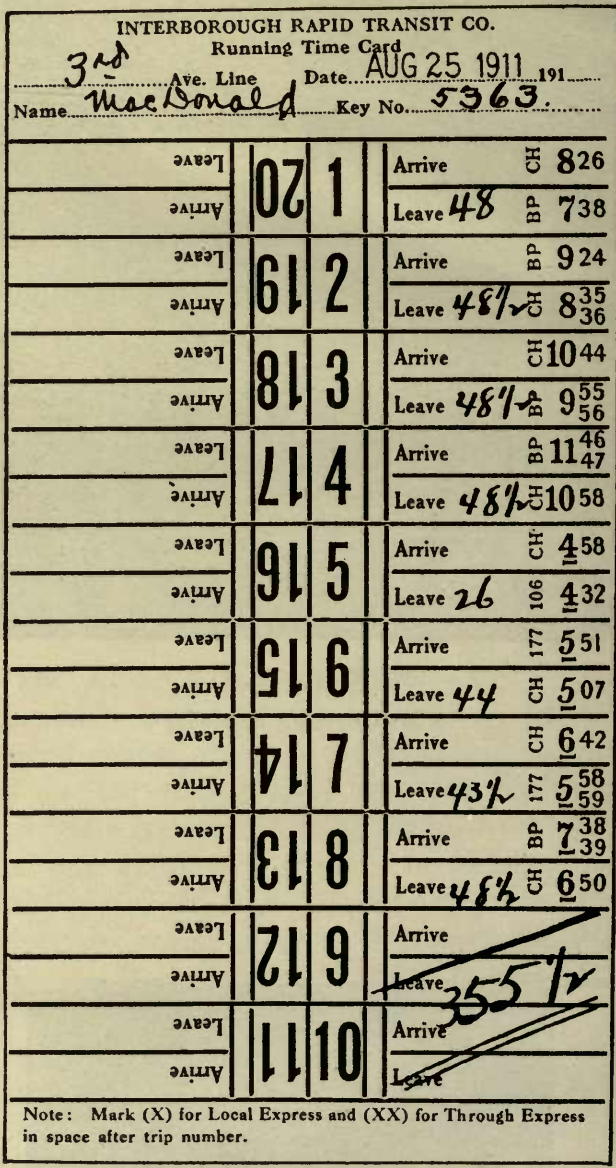


Engraved Motorman's Key
for Rico Coasting Recorder

Rico Terminal Clock

Rico Terminal Clock Automatically Records the Running Time

(For use with Rico Coasting Recorder)



INTERBOROUGH RAPID TRANSIT CO.
Running Time Card

3rd Ave. Line Date AUG 25 1911 191
Name MacDonald Key No. 5363.

Leave	20	1	Arrive	CH	8 26
Arrive			Leave 48	BP	7 38
Leave	19	2	Arrive	BP	9 24
Arrive			Leave 48½	CH	8 $^{35}_{36}$
Leave	18	3	Arrive	CH	10 44
Arrive			Leave 48½	BP	9 $^{55}_{56}$
Leave	17	4	Arrive	BP	11 $^{46}_{47}$
Arrive			Leave 48½	CH	10 58
Leave	16	5	Arrive	CH	4 58
Arrive			Leave 26	106	4 32
Leave	15	6	Arrive	177	5 51
Arrive			Leave 44	CH	5 07
Leave	14	7	Arrive	CH	6 42
Arrive			Leave 43½	177	5 $^{58}_{59}$
Leave	13	8	Arrive	BP	7 $^{38}_{39}$
Arrive			Leave 48½	CH	6 50
Leave	12	9	Arrive		
Arrive			~~Leave~~ 355½		
Leave	11	10	~~Arrive~~		
Arrive			~~Leave~~		

Note: Mark (X) for Local Express and (XX) for Through Express in space after trip number.

Running Time Envelope Showing Facsimile Record from Rico Terminal Clock

Rico C & S Recorder

Figure 3-A
Exterior View

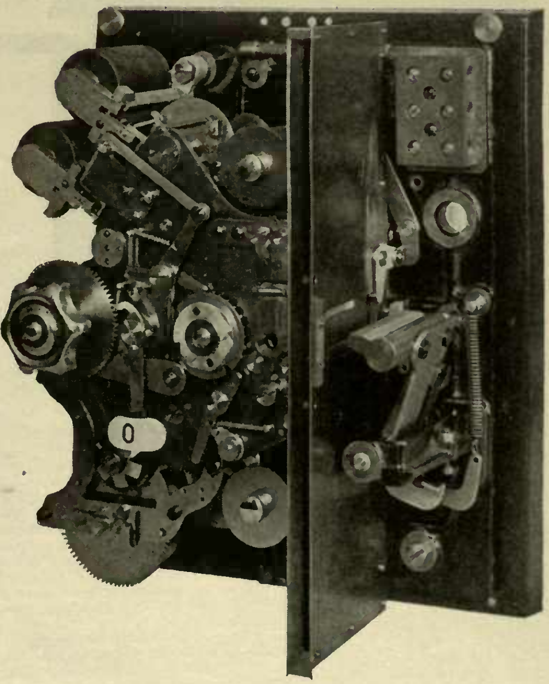
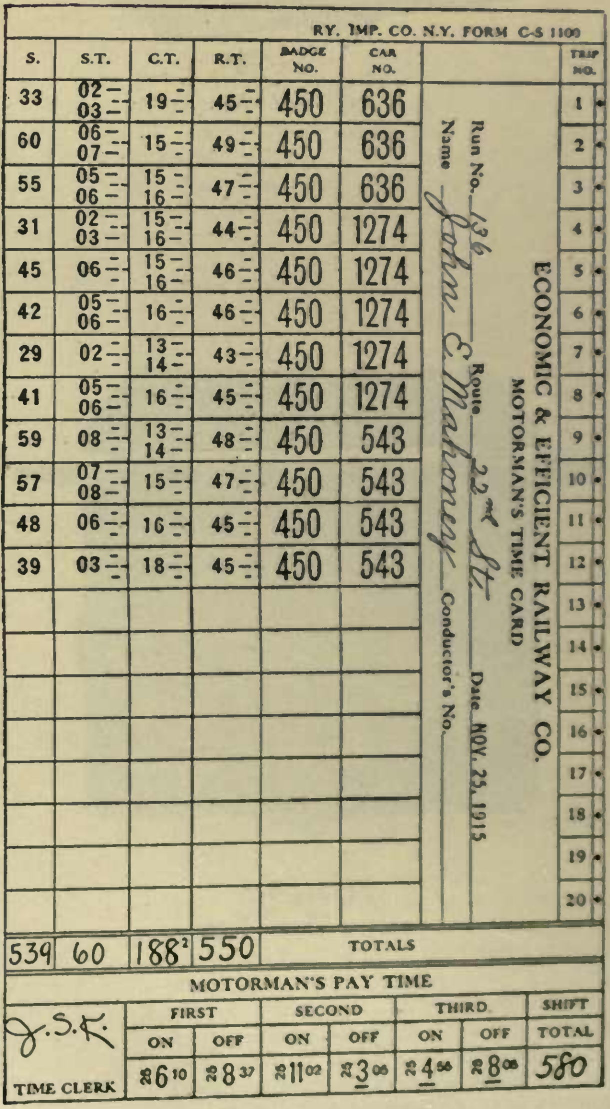


Figure 4-A
Interior View—Cover Removed

Figure 5-A
Engraved Motorman's Key



RY. IMP. CO. N.Y. FORM C-S 1100

ECONOMIC & EFFICIENT RAILWAY CO.
MOTORMAN'S TIME CARD

Run No. 136 Route 22nd St. Date NOV. 25, 1915
Name John E. Mahoney Conductor's No.

S.	S.T.	C.T.	R.T.	BADGE NO.	CAR NO.	TRIP NO.
33	02 03	19	45	450	636	1
60	06 07	15	49	450	636	2
55	05 06	15 16	47	450	636	3
31	02 03	15 16	44	450	1274	4
45	06	15 16	46	450	1274	5
42	05 06	16	46	450	1274	6
29	02	13 14	43	450	1274	7
41	05 06	16	45	450	1274	8
59	08	13 14	48	450	543	9
57	07 08	15	47	450	543	10
48	06	16	45	450	543	11
39	03	18	45	450	543	12
						13
						14
						15
						16
						17
						18
						19
						20
539	60	188^{2}	550	TOTALS		

MOTORMAN'S PAY TIME

	FIRST		SECOND		THIRD		SHIFT
	ON	OFF	ON	OFF	ON	OFF	TOTAL
J.S.K. TIME CLERK	6^{10}	8^{37}	11^{02}	3^{06}	4^{56}	8^{08}	580

Figure 6-A
Rico C & S Recorder—Card Form Record

Rico C & S Recorder Relay

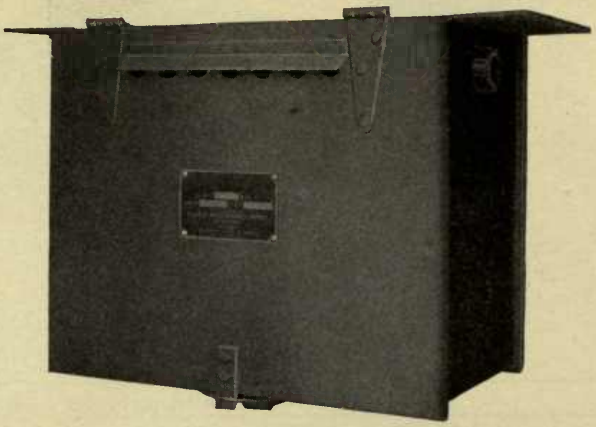


Figure 7-A
Exterior View—Front

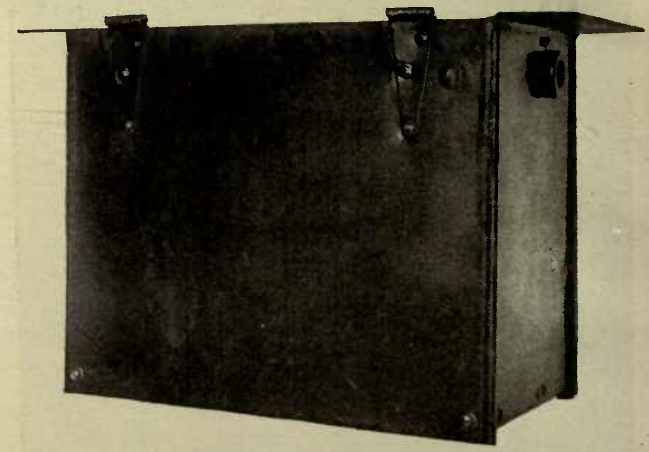


Figure 9-A
Exterior View—Back

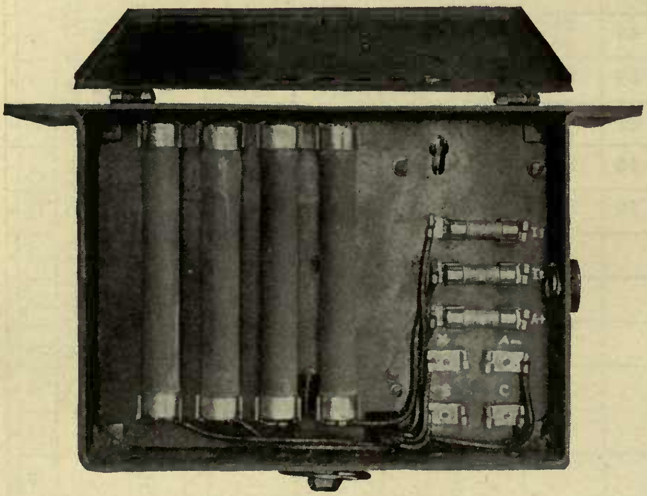


Figure 8-A
Interior View—Front

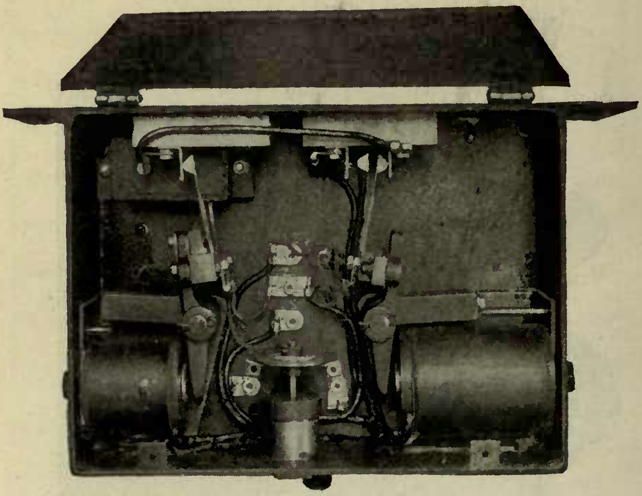


Figure 10-A
Interior View—Back

The Rico Coasting Recorder is not a watt or ampere-hour meter, which obviously can measure only the power input; but it is the correct tool and accurate yard-stick for measuring the motorman's efficient utilization of the time-element factors that control the *efficient use* of the power input.

The fundamental principles, considered and analyzed, as to the effect of the controlling time-element factors, demonstrate that increased efficiency, developed through a correct method efficiency checking system, means not only reduction in power input, but reduction in brake shoe wear and motor temperature, thereby reducing the maintenance expenses.

Likewise, it is also obvious that the efficient utilization of the time-element factors results in better conformance to the established schedule speed, with less variation between the maximum attained speed and the average schedule speed; also that such an efficiency checking system must develop a standard of alertness in the motorman—all controlling factors in reduction of accident liability.

The efficiency checking system based on the Rico Coasting Recorder, when applied in practical operation, has generally developed such a standard of efficiency in handling the car equipment that schedule speeds have been increased and efficiently maintained.

TABLE I-A

The Ratio of *increase* "Percent Coasting" to *decrease* "Percent Power" has been determined by carefully conducted Tests, under actual conditions of operation, upon metered sections or systems of several typical Railway Companies, covering widely divergent operating conditions, as follows:

NAME OF ROAD	Ratio of Increase Percent Coasting to Decrease Percent Power
San Francisco-Oakland Terminal Railway	1% : 1.22% Saving
Denver Tramway Company	1% : 1.1% Saving
Pacific Electric Railway	1% : 1.06% Saving
Metropolitan West Side "L," Chicago	1% : 0.98% Saving
Bay State Street Railway	1% : 1.05% Saving
Washington Railway & Electric Co	1% : 1.02% Saving
Northern Texas Traction Co	1% : 1.2% Saving
Los Angeles Railway Co	1% : 1.07% Saving
Empire United Railways	1% : 0.78% Saving
Milwaukee Electric Railway & Light Co	1% : 1.07% Saving
San Antonio Traction Co	1% : 0.99% Saving
Boston Elevated Railway Co., Surface	1% : 1.09% Saving
Elevated	1% : 0.94% Saving
Syracuse Rapid Transit Co	1% : 1.19% Saving
Interborough Rapid Transit Co	1% : 0.91% Saving
Chicago Railways Co., Surface	1% : 0.91% Saving

The above ratios obtained from actual tests appear slightly higher than the ratios indicated from several Speed Time and Power Diagram Analyses. It should be borne in mind, however, such analyses assume constant voltage conditions, while in practice the decreased power resulting with coasting, causes less voltage drop and hence corresponding improved voltage conditions, with consequent improved changes in the motor performance for such actual conditions of operation, thereby probably resulting in a higher ratio obtainable in actual operation.

The results obtainable by the Rico Coasting Recorder, Correct Method Efficiency Checking System, may be summarized as follows:

[I] EFFECT ON POWER:

1. A saving in power consumption; the percentage of saving in power being approximately directly proportional to the increased percentage of coasting. (See Table I-A.)
2. A lowering of the peak on the power station.
   a. Due to the decrease in average power consumption, per car, per hour of operation.
   b. Due to the motorman's time in accelerating the car becoming more uniform and approximating the calculated acceleration time, based on the motor equipment characteristic performance for established schedule speed and traffic conditions.

[II] EFFECT ON BRAKE-SHOE MAINTENANCE:

Due to saving in direct brake-shoe wear. The energy to be dissipated in brakes varies as the square of the speed at the time of applying the brakes. Therefore, as a portion of the energy stored in the car is utilized in coasting, the speed at the time of applying the brakes is less, with resultant reduction in the energy to be dissipated by the brakes.

[III] EFFECT ON EQUIPMENT:

1. Decrease of armature and other motor troubles due to smaller rise in temperature, resulting from lower average amperes passing through the motor.
2. Decrease in wear and tear on equipment in general, resulting also in saving in maintenance and renewals of wheels, gears, etc.

[IV] EFFECT ON RUNNING TIME:

The regular running time is made more uniform per trip and closely approximates the schedule running time, due to the system of checking by the use of the Rico Coasting Recorders.

[V] EFFECT ON ACCIDENTS:

Decrease of accident liability.

a. Due to lowering of maximum attained speed, hence resulting in more uniform speed.
b. Due to more uniform braking.
c. Due to power being on for a smaller percentage of the time, thus leading to one less operation to stop or reverse the car, as necessity may demand.
d. A motorman to obtain maximum coasting time must at all times be on the alert to avail himself of all opportunities; therefore, as a natural deduction the motorman ceases to be an automaton. He becomes a thinking operator on the alert at all times. Hence under these conditions accidents to pedestrians and traffic vehicles will diminish.

Rico C & S Recorder

Both the consideration of the fundamental principles of car operation efficiency and the results obtained on the large number of representative railway systems, establish the Rico Coasting Recorder as a correct principle and an effective "tool" for attaining the increased efficiency, which in practical operation is attainable only through the human equation—the individual motorman.

Not all the time-element factors, that have been shown as controlling and determining possible efficiencies for given conditions are within the control of the motorman. For illustration, the motorman has only part participation in the resultant duration of stop, while the schedule speed and number of stops are wholly determined by others and by the traffic conditions.

The fundamental principles demonstrate that for a given car and its equipment of given gear ratio, there is an economical schedule speed, dependent upon the traffic conditions and the unit costs of power and platform expense.

The curves showing the relation of total power and platform expense to schedule speed, Fig. 14, p. 36, Chapter II, hereof, show a rapid increase in the cents per car-mile cost, for power and platform expense, for a comparatively short range departure either above or below the most economical schedule speed. It is readily apparent from these curves that material increase in operating expenses, per car, per year, must result from improper schedule speeds, for given car equipment and traffic conditions.

The most economical schedule speed for a given car and its equipment, for given power and platform unit costs, is a function of the average number of stops per mile, coupled, of course, with the average duration of stops as illustrated in Fig. 15, p. 36, Chapter II, hereof.

The attainment of possible efficiencies in car operation, in practice, means not only improvement in the efficiency of the motorman, under any existing schedule speed and traffic conditions, but also means the accomplishment of additional attainable efficiencies from economical schedule speeds based on the analysis of the accurate record of traffic conditions, for each hour and minute of each car, on every line and route of a railway system.

To meet the requirements for the attainment of these additional efficiencies the Railway Improvement Company, manufacturer of the Rico Coasting Recorder, has developed the Rico Coasting and Service Recorder, designated for commercial abbreviation, the Rico C & S Recorder.

The Rico C & S Recorder is a development based on the essential features of the Rico Coasting Recorder, modified in design to give in printed form the essential factors, encountered in practical operations, that affect car operation efficiency.

The Rico C & S Recorder equipment, necessary for each electric car or each multiple unit train operated, consists of the Rico C & S Recorder, see Figs. 3-A and 4-A, with its electric relay, see Figs. 7-A to 10-A, inclusive.

The record from the Rico C & S Recorder is printed on a card form. Fig. 6-A is a facsimile, typical of the record and data obtainable from the Rico C & S Recorder equipment. The identification of the motorman is established by the motorman's engraved key (Fig. 5-A), inserted to operate the Recorder and obtain the record.

Referring to Fig. 6-A, from left to right, the card record shows for each trip of a run or between any designated points for which the information is desired, the following:

COLUMN S., the record of the total number of stops;

COLUMN S.T., the record of the aggregate total time in minutes, consumed by the total number of stops;

COLUMN C.T., the coasting time in minutes;

COLUMN R.T., the actual total running time, in minutes, and includes in such total, the aggregate stopping time (Column S.T.);

COLUMN BADGE NO., the number of the motorman operating the car, when the record was obtained;

COLUMN CAR NO., the number of the car on which the record was taken;

COLUMN TRIP NO., at the extreme right, is self-explanatory. It acts as a guide and gage to the motorman for placing the records consecutively on the form card.

The columns S., .S.T., C.T., and R.T., are totaled for the motorman's daily operation, and entered as indicated.

The card can be arranged with space at the bottom, as shown in Fig. 6-A, for entry by the time clerk of the motorman's pay time, for the day. This entry can be made by the time clerk, or by an automatic time clock, showing the day of the month and the motorman's exact time on and off duty, leaving only the footing of his automatic record of pay time, to be entered by the time clerk, as shown on Fig. 6-A. This particular motorman's total pay time for November 25, 1915, was 580 minutes or 9 hours and 40 minutes for the day.

The record shown on the card form, Fig. 6-A, is taken as typical of the twelve trips, made by Motorman No. 450, on Nov. 25, 1915, his operations being on a route, covering in each trip a distance of 7½ miles, with a schedule, speed of 10 miles per hour, requiring 45 minutes schedule time per trip.

Based on the foregoing the record of the day's operations can be analyzed as follows:

Total number miles, for all trips.....	90 miles
Total number stops, for all trips.....	539
Average number stops per mile, for all trips..........................	5.99
Total aggregate time (S.T.) consumed in total stops of all trips..	60 mins. or 3600 secs.
Average duration of stop, for all trips	6.67 secs.
Total running time (R.T.) being the earning or income time of the Car Crew, for the Railway Company, for all trips....................	550 mins.
Coasting time (C.T.), for all trips.....	188½ mins.
Per cent coasting, the measure of the motorman's efficiency standing, for all trips, being 188½ divided by 550 or..........................	34.2%
The earning or income time (R.T.) of the car crew for the company, 550 minutes is checked at a glance, for comparison with the total pay time, entered by the time clerk, for the day of.......................	580 mins.

Rico C & S Recorder an Automatic Analyst of Railway Operation

The wonderful possibilities of the record available by the use of the Rico C & S Recorder appeal at once to the practical railway operator. With it he has at his command an automatic analyst which can tell him not once a year, once a month, once a week or once a day the vital factors that affect operating costs and service standard results, but a device that reveals such factors from minute to minute in the operation of each car!

The Rico C & S Recorder, it is apparent, possesses all the advantages and secures all the results obtainable from the Rico Coasting Recorder.

The Rico C & S Recorder, also, makes available for study and analysis the constant, accurate and automatic record of the vital factors of varying traffic conditions for utilization in the determination of economical schedule speeds and for analysis of the equities of standards for service.

The operations required to obtain the record from the Rico C & S Recorder are quickly made and "foolproof." In the making of the record all the type dials return to zero position for each dial after making each trip or desired period record, thus facilitating the clerical work required in making any desired footings for analysis.

The card form of the Rico C & S Recorder record makes it more convenient for handling, reference and preservation than the tape form record used in the Rico Coasting Recorder.

The principles analyzed and discussed in Chapter II demonstrate that the obtainable possible efficiency for the operation of a given car and its equipment can be calculated for any given schedule speed, with the factors known as to the average stops per mile and the duration of the stops, etc.

Therefore, with the Rico C & S Recorder record available the correct relative measure of the motorman's efficiency is not only shown by his percent coasting, but the data are available to check his actual efficiency with the obtainable efficiency for the schedule speed under the recorded traffic condition factors.

The Rico C & S Recorder removes the construction of economical schedule speeds from the realm of experimental determination and guess-work, as the data are available for the schedule builder, to determine the economical schedule speed which will fit the available equipment for the actual traffic conditions.

The Rico C & S Recorder records make available the data for determination of the suitability of the gear ratio of the equipment from the record of the traffic condition requirements.

The records of the number of stops and duration of stops, in connection with the passenger record data, can be utilized to determine the efficiency in practical operations of entrance-door designs, step heights, seating arrangements, etc., thus giving definite data for determining their adoption. Similarly, the adaptability and advantages of high efficiency bearings, methods for lubrication, etc., can be checked, having the schedule running time, coasting time, etc., obtainable therewith, available as an automatic printed record, from the car or cars so equipped, for comparison with similar records on the existing car equipment.

Skip Stop and Service Standards

Every railway executive and transportation manager has long realized that the number of stops affects not only the cost of service, but the limitations of the service attainable with available equipment.

The American Electric Railway Association has made extended investigations upon the study of the effects of the number of stops. Such studies being determined only by personal investigation surveys, have necessarily been limited in scope, but have pointed to the unerring conclusion that the number of stops is a vital factor in the costs and standards for service.

In Chapter II, p. 39, we have shown how the advantages and value of the Skip Stop on the quantity and time for transportation service is a matter of exact calculation for given equipment and conditions.

The great difficulty has been that no real information as to the number of stops and the time consumed thereby is known in reference to any railway's regular practical operations.

The Rico C & S Recorder gives this data for every route and car of the system. With its record available, the railway operator knows the limitations placed upon his service by the existing conditions of stops and can determine by calculation and present in tangible proof and form the betterments in service obtainable by reducing the number of stops through some reasonable skip stop rule or regulation.

Furthermore with the record of the Rico C & S Recorder available, the proof for the unequitableness or hardship of hasty and often ill-advised service standards, can be established.

Power Measurement Not An Effective Efficiency Check

The use of a watt or ampere-hour meter naturally suggests itself as a method for checking car operation efficiency.

It is self-evident that neither the Rico Coasting Recorder or the Rico C & S Recorder nor the meter (watt or ampere hour) will of themselves effect any savings, except by the utilization of the records obtained as an efficiency checking system, to improve thereby the efficiency of the human equation—the individual operator.

The fundamental principles for car operation efficiency demonstrate that the efficient utilization of certain time-element factors solely controls the ultimate results. Unless the efficient utilization of these time-element factors is checked and efficiency obtained by the correct method of checking the controlling time-element factors, the best obtainable efficiency cannot be approached in practical operations.

The principles analyzed and summarized in Chapter II establish the measurement of the controlling time-element factors as the correct basis for an effective efficiency checking system. The logical and fair consideration and analysis of the principles involved, demonstrate that the meter does not measure up to the requirements,—the Coasting Recorder *does*.

As shown on p. 35, Chapter II, hereof, the measurement at the car of power input only is an incorrect and misleading measure of the motorman's actual efficiency. Such measurement means nothing, unless analyzed in reference to the component time-element factors, which control and determine the power input;

for as demonstrated, the kw.-hrs. per car mile input to the car may increase in excess of 33 ⅓ per cent, due to the variations in such factors (encountered in practical operation) and yet the actual efficiency of the motorman, in the use of power, remain unimpaired.

The incorrectness of power input measurement as a basis of motorman rating and its disadvantages as an effective method for developing efficiency of the motorman is apparent from Columns 3 and 4 of Table I, p. 39, Chapter II, hereof; from which table it is to be noted that motormen D, F, C and E are given rated standings not in accordance with their actual efficiency, as shown in Column 1 of said Table; also it is to be noted that motorman C, who operated under the most severe traffic conditions of all (see Fig. 17, p. 37), is particularly discriminated against on the power measurement basis of rating.

The preceding is further illustrated by the log sheet data from a test conducted by one of the large operating companies, as follows:

With the same car operated over the same route, Motorman A made a trip run, carrying a total of 70 passengers, averaging 6 stops per mile and used 2.42 kilowatt-hours per car mile by meter measurement; Motorman B made the next trip run, carrying a total of 101 passengers, averaging 7.8 stops per mile and used 2.42 kilowatt-hours per car mile, by meter measurement.

Now, based on power input measurement, these respective motormen operated with like efficiency, though even a casual knowledge of physical and mechanical principles indicates more energy required for B than A; the Rico Coasting Recorder reading on the log sheet tells the story of their relative efficiencies, as the per cent coasting of A was 18.9 per cent, while the per cent coasting of B was 30.2 per cent.

Would anyone suggest that efficiency can properly be developed through a checking system which indicated that A and B, making successive trips in regular operation, are alike in efficiency? Yet such would be their respective ratings, if based only on measurement of power input!

Because statistical data and the unit costs of railway accounting are based on the kilowatt-hour unit, it is possibly a natural error to conclude that the measurement of power input at the car is a proper method to check the motorman's efficiency.

However, it must be conceded that a fair-minded and reasonable consideration of the practical and technical principles involved will establish the fallacy of such power measurement being an effective, "Square Deal" efficiency checking system.

If the operating executive, in selecting an efficiency checking system for purchase, does not go into the fundamental and basic principles involved (which demonstrate conclusively the time-element factors, control and determine the ultimate power input), how can it be expected that a motorman will analyze the apparent discrepancy of the widely varying power input readings that must result (as hereinbefore shown) from variations in practical traffic conditions?

Results Desired—How Obtainable

The real result of interest to the operating executive staff is reduction of power at the source of supply, where the costs for power originate.

To obtain such results, the executive staff, by a correct method and means, should constantly and consistently check the individual motorman's efficient utilization of the controlling time-element factors.

The efficient utilization of such controlling factors is relatively correctly measured, under any and all conditions of practical operation, by the coasting; any increase coasting, for given conditions encountered in practice (with schedule speed maintained), means more efficient utilization of the controlling time-element factors and consequently a reduction of power.

When equipped with the Rico Coasting Recorder or the Rico C & S Recorder Efficiency Checking System, the motorman (maintaining schedule speed) has to deal only with the increase of his coasting time, which is automatically recorded in printed form for each trip. Thereby he obtains the correct relative measure of existing efficiency—a guide and monitor for him and record data for the executive staff to compare with possible obtainable efficiency.

The simplicity and effectiveness of such a system is apparent when compared with an efficiency checking system based on power measurement records on the car. To mean anything intelligible such a system involves laborious analysis and correction for the multitudinous variations encountered in traffic operating conditions.

The time and expense required are likely to cause such analysis of power measurement records to be "passed up" by the operating executive staff; but in any event, such records, analyzed, or unanalyzed, logically lead to the bewilderment and discouragement of the motorman,—the human equation through whom efficiency results must be obtained with any system for checking efficiency.

Railway companies generally emphasize the desirability of coasting, as witnessed by the space devoted thereto in practically every company's book of rules for motormen, also by their educational directions for the motorman to coast by means of inspectors, instructors, lectures on operation, tickler reminder cards, etc. This certainly demonstrates an appreciation on the railway's part that coasting is a necessary practical factor in obtaining increased efficiency. Yet, paradoxically, many companies overlook the vital necessity for a constant, individual, accurate and effective checking record of that coasting,—which coasting the fundamental principles demonstrate is the correct relative measure of the motorman's actual efficiency.

Time and money are expended in following up and keeping records of almost all other expenditures or possible leaks from income, while the effective checking of the motorman's operations and efficiency in car operation, a field for prolific results in possible savings, is allowed by many companies to pass with the generalities of indirect methods and measures, having no other check than the fallible one of personal inspection by several men.

The statement is often heard: "We have sign-boards indicating the point at which power is to be thrown off for a station stop, thus fixing a period for coasting before applying the brakes, to make the station stop." How can a company know whether the instructions on the sign-board are followed, unless a constant, accurate record of the motorman's operations are available? Certainly a human inspector can check only a small percentage of car operations!

We feel that the purpose of this paper will be accomplished if it shall lead to the consideration of the controlling and determining effect of time-element factors on operating results.

Time is the essence of railroading! The time essence applies to every railway regardless of type and character of traffic conditions. When the time-element factors are considered there will be no difference of opinion as to the correct method for checking efficiency, or as to the justification of the necessary investment for a correct method efficiency checking system.

Results from Practical Operation

Thus far, the purpose of our endeavor has been to point out the fundamental principles involved in car operation efficiency and the application of such principles to practical operations; together with consideration of the adaptability of available commercial equipment for checking, in practice, the efficient utilization of the time-element factors, demonstrated as controlling the efficiency results of practical operation.

Therefore, it is now desirable to present some of the results actually obtained and the methods for obtaining same in practical operations with the Rico Coasting Recorder.

The operating results of more than 8,000 cars (on thirty-seven railways) whose operations are checked with the Rico Coasting Recorder Efficiency Checking System are available. These results show 10 per cent to 25 per cent reduction in power used for traction purposes, 15 per cent to 45 per cent reduction in brake shoe maintenance and a material though less tangible reduction in motor equipment maintenance and accident liability.

From the preceding paragraph it appears that nearly two score electric railways are using Rico Coasting Recorders to check the motormen, just as they use fare registers and fare boxes to check the conductor.

The several operating conditions of these companies represent the widest possible range of topography, of speed, of congestion in traffic, car and train service, and of labor conditions.

The success of the Rico Coasting Recorder, therefore, is independent of local physical and operating traditions. The progressive operator, eager to eliminate every form of waste and to exploit any aid to efficiency, should not longer ignore the lesson taught by the results, from operating companies using Rico Coasting Recorder installations.

It is easier to create than to maintain enthusiasm; the Rico Coasting Recorder Efficiency Checking System not only creates but maintains enthusiasm.

For example, on the Denver Tramway Company, prior to the installation of Rico Coasting Recorders in 1912, the average per cent coasting was 11 per cent; since the installation this has risen steadily and consistently from the 11 per cent in 1912 to 40 per cent for 1915, with a corresponding reduction in power for traction purposes of 25 per cent and increase in life of motor armatures of about 50 per cent.

The San Francisco-Oakland Terminal Railway Company, during the months of February to May, inclusive, 1914, installed Rico Coasting Recorders to check the operations of its 360 cars. The company purchases its power, and based on the respective kilowatt-hours per car mile for the calendar year 1914 compared with 1913 operations, there was saved the sum of $28,718.04; similarly the savings in power for the calendar year 1915 compared with 1913 power aggregated $56,252.72.

The San Francisco-Oakland Terminal Company's cost of brake shoe maintenance showed a decrease of $2,896.40, its maintenance of electrical equipment a decrease of $7,804.86; also injuries and damages payments a decrease of $11,447.67 for the year 1915. This company states: "Without question a large portion of this saving is due to the beneficial results obtained through the use of Coasting Recorders."

The foregoing and similar available examples are clear proof that Rico Coasting Recorder records are not temporary but permanent and increasing gains in achieving operating economies.

Illustrative of the methods used in familiarizing motormen with the use and purpose of the Rico Coasting Recorder, herewith, (pages 24 and 25) is the copy of a railway company's advisory bulletin to motormen, the substance of which can easily be modified for the conditions of any railway company.

Co-Operative Engineering Service

The Railway Improvement Company, manufacturer of the Rico Coasting Recorder and the Rico C & S Recorder, emphasizes the fact that it is not merely selling a device, but a co-operative engineering and transportation service.

Rico installations are based upon a most exacting study and analysis of the customer's power, equipment and schedule conditions, etc.

Rico installations are introduced by a thorough system of instruction in the correct way to operate a car.

Rico installations are accompanied by an organization which provides and supplies competitive records, insignias, etc., thus keeping up the interest of the men; and which arranges for any re-instruction necessary to maintain or improve coasting results.

Rico installations are furnished with all necessary forms to keep correct maintenance and cost records for the Rico equipment.

Finally, the Railway Improvement Company acts as a clearing house for the exchange of results by and experiences of Rico users. The Rico equipment has such wonderful possibilities in obtainable results, when rightly introduced and rightly used, that neither the purchaser nor the seller can look upon it as a mere piece of mechanism. The staff of the Rico organization is schooled in the training and experience necessary to provide and direct, co-operatively, the means and methods for ac-

"Letterhead of Railway Company"

ADVISORY BULLETIN

*No.*________

To Motormen:

Now that all the cars of this company have been equipped with Rico Coasting Recorders, no doubt some of you motormen are probably asking what is the use of all this expense and what good are the coasting recorders.

Have you ever read Rule No. 266, Economical Use of Current, in your book of rules and regulations? Are you economical in the use of your power? Are you handling the car in the best possible way? I think I heard somebody say, "Yes, I believe I am doing as well as the next man." How do you know you are without some device to show you what you are doing from trip to trip and day to day?

Now stop and think what happens when you run a car. First, current is applied, by steps, through the controller and the car gets up speed. When you have cut out all the resistance the controller is at a running point and the speed of the car has very nearly reached its limit. When you have a stop to make, you throw off the power and then apply the brakes. Why do you have to apply brakes? That is simple: when the power is applied a certain amount of energy is used to bring the car up to the speed, and then, to keep up this speed, a constant amount must be applied to overcome the resistance of the air and the friction of the moving parts, and the car has a certain amount of energy stored up in it. Now, suppose after you have thrown off the power and you do not apply the brakes. The speed of the car will gradually decrease and finally come to a stop. In other words, the energy that is stored up in the car will carry it quite a distance without further application of power. You say, "Yes, sure, but if that is done it will take longer to cover that distance and if I tried it I would lose time." There is no doubt about that, but don't carry this method too far. Turn off the power far enough back from the stop and let the natural forces reduce a portion of the car speed, then apply the brakes and bring the car to a nice, easy stop. Every time you do this you are saving power by using a portion of the energy that is stored up in the moving car.

The Rico Coasting Recorder shows whether you are availing yourself of this opportunity. It is a device which registers the actual time that the car is moving without power and without application of brakes. An application of either power or brakes instantly stops the measuring mechanism of the Recorder.

Experiments have shown that by careful operation you can coast more, still maintaining the running time, and by having your car under better control decrease accidents, at the same time helping your company by helping to utilize the power more efficiently.

Now you say, "I am going out and pay a little more attention to the way I use power. How can I increase my coasting and still keep up my record as a careful man?"

First: The more attention you pay to your operation, the less trouble you will have.

Second: The more attention you pay to your operation, the more coasting you will do.

Third: The greatest acceleration in miles per hour, for the general average conditions of operation, can be obtained only by a strict adherence to the time rate of acceleration. You have received instructions as to the proper rates of acceleration, determined as suitable in practical operations, for our company's respective equipments. The great trouble in practice is not, generally, too rapid acceleration, *but too irregular* acceleration; the motorman pausing longer than he should on one point, only to rob the next of its proper time element—or even passing over the same without a pause.

FOURTH: Energy once stored in a car can be dispelled only through coasting or braking. One application of air with a graduated release (where possible) is good practice. The fewer applications of air ("fanning the air") in stopping a car, the higher the coasting obtainable.

FIFTH: *Length of stop* is materially lengthened by the failure of the "Rear End" operator to give the bell promptly—or because the "Front End" operator is not on the alert to start his car when "given the bell." Length of stop is also materially increased when the operator indulges in "inefficient braking." Regular passengers soon come to know the careful operators on their lines and will leave their seats when approaching their regular stopping points and are all ready to alight when car comes to a standstill. The "inefficient braking" operator has the opposite effect on his passengers, thus causing longer stops.

SIXTH: *Increased number of stops* per mile, on certain trips, are often caused by the operator "dragging the line," thus carrying not only his own normal "Run Load," but part of his "followers."

SEVENTH: A good coasting record, day by day and week by week, is not brought about by spurts but by the adding up of the coasting in small amounts. You may try to secure a long coast where coasting is apparently easy only to lose it in small amounts when you find that you have lost time and have to make it up. The highest records are made by paying attention to the small amounts obtainable just before stops, traffic slow-downs, etc. Unless it is an emergency case, make a practice of throwing off the power, say, 3 or 4 seconds before applying the brakes. This increase in coasting is not noticed by casual observation but results in a great increase in *total* coasting time at the end of each trip or at the end of the day. Increased coasting obtained in this manner does not affect the schedule running time, as the momentum of the car is not sufficiently retarded during the coasting periods, to be noticeable.

In carrying out the foregoing suggestions, see what you can do by utilizing the stored-up energy of the moving car in the following ways:

[1] Coast behind a leading car instead of using power till you have to make a heavy application of brakes. Keep far enough behind so that all his stops will not cause you to stop. You can't pass him on the same track, and you can utilize this time by coasting.

[2] Coast to a passenger or bell stop. Unless the bell is short or the signal by a passenger is given late, you can always throw off a few seconds before applying brakes and you will be surprised how it adds up at the end of the day.

[3] Coast to a traffic stop. When a wagon or other vehicle gets in the way, throw off the power and coast while ringing the gong. You will have your car under better control in case of having to make a quick stop, or if the track is cleared you can again apply power, thus losing very little time.

[4] Coast to curves and sidings. Never run into a short radius curve at a high rate of speed. Don't keep the power on until the last moment and then apply brakes. Shut off the power far enough back so you get a few seconds coasting, then if you find you have misjudged the distance apply the brakes until the speed is reduced, release and coast around the curve.

Approved:

[SIGNED]. . . . .
Superintendent of Transportation.

[SIGNED]. . . . .
General Superintendent.

complishing the possibilities of Rico equipment in the practical operations of railway companies.

Monetary Value of Obtainable Results

The results obtained in the operation of a given railway can or should be capable of determination from the analysis of the operating statistics of such railway.

The obtainable possible results can be determined by calculation from the application of the principles herein discussed (in Chapter II) to the analysis of the company's equipment in reference to existing or adopted schedule speeds, number stops per mile, etc., for the average operating conditions.

The difference between such obtainable results and the existing results represents the savings possible by increased efficiency in operation.

We believe a fair-minded consideration and analysis of the whole problem and the factors entering it will be convincing as to the large possibilities for increased efficiency even to those who, heretofore, have contemplated their present operating results with satisfaction.

The results obtained by railway companies utilizing the Rico Coasting Recorder Efficiency Checking System show net savings, after deducting maintenance and operating expenses for the Rico equipment, ranging from $50.00 to $200.00 per car per year, dependent upon the conditions of operation, the cost of power, etc. The analysis of results obtained in practice, indicate that for the conditions of the average company, approximately the entire cost of the Rico Coasting Recorder equipment can be saved each year of its operation.

The utilization of the Rico C & S Recorder (see p. 18), now offered for commercial use, makes possible even greater net savings than those accomplished by the use of the Rico Coasting Recorder.

The increased efficiency obtained through the effective utilization of the controlling time-element factors, effects a reduction in the "demand" on the generating station and distribution system (see p. 40, Chapter II). The consideration and analysis of these matters for actual conditions in operation shows that for each dollar invested in the Rico Coasting Recorder or Rico C & S Recorder Efficiency Checking Systems from $5.00 to $10.00 in power generating, sub-station and distribution system investment is not required or is available for other purposes, dependent upon conditions and the existing type of construction.

Therefore, there are available, not only increased net earnings from operating Rico equipment, but there is saved or released a capital investment that is several times greater than the capital investment for the Rico equipment.

Yields Highest Net Return on Investment

The investigation of the results obtained in practical operation will demonstrate that either the Rico Coasting Recorder or the Rico C & S Recording Efficiency Checking System yields higher net returns on the investment, after allowing operating expenses, including fixed charges, than can be obtained from any other system available commercially for checking the efficiency of car operation.

Deferred Payments Purchase Plan

In conclusion, it may be mentioned that the purchase of Rico Coasting Recorder and Rico C & S Recorder equipment can be arranged through the Railway Improvement Company by mutual agreement, on the basis of deferred payments, making possible the payment out of the net savings obtainable and in many instances with a possible handsome surplus remaining in addition to the requirements for meeting such deferred payments.

Chapter Two

Fundamental Principles of Car Operation Efficiency

Chapter Two

Fundamental Principles of Car Operation Efficiency*

A Study of the Practical and Technical Principles Involved in the Use of the Time-Element Factors in Railway Operation, Particularly in Determining the Most Economical Rates of Acceleration, Braking and Speed from the Standpoint of Power and Platform Costs

By C. C. CHAPPELLE

Consulting Engineer and Vice-President
Railway Improvement Company

EVERY traction company executive and his operating staff are confronted with the necessity for increased economies in operation on account of the greater cost of money needed to meet the constant demand for new capital, and because the general business depression and the competition of the automobile tend to curtail gross earnings. Obviously, increases in gross earnings are not to be expected under conditions generally existing.

In searching for means of reducing operating expenses attention would naturally first be directed to the motor, but the manufacturers of motor equipment cannot be expected to secure efficiencies substantially higher than those already obtained. Economies are, of course, obtainable through reduction in weight of cars and equipment, and the possibilities of one-man operation are well recognized.

Unfortunately in the average case the investment in present equipment is so large that it is rarely practicable to write off the cost of old equipment with the economies obtainable from the new. It follows, therefore, that the logical method of increasing net earnings is to reduce operating expenses by securing increased efficiency with either old or new equipment.

One of the greatest needs of the present time in the railway field is a better understanding of the principles involved in the attainment of the high efficiencies desired, and of the practical application of these principles to the ordinary every-day operations of electric railway systems.

The first point to remember in this connection is that time is the essence of railroading before and after construction. Success depends upon the efficiency with which railway operations are performed in established intervals of time.

In considering and analyzing the effective utilization of time on a railway in operation we must apply the same principles which are used in determining by calculation the power and equipment requirements of a railway prior to its construction.

In determining the capacity of the necessary power plant and selecting the motor equipment for the rolling stock of a projected road, speed-time and energy diagrams based on the proposed schedule speeds, average number of stops per mile, etc., form the basis of the calculations. This same method is applied by motor manufacturers in determining the suitability of new equipment for the average conditions of roads which are actually in operation.

As a basis for such diagrams seven average operating characteristics must be assumed or determined for each car route of a system as follows:

[1] The average weight, including average load, of a typical car equipped with typical motors operating with a given gear ratio.

[2] The average schedule speed.

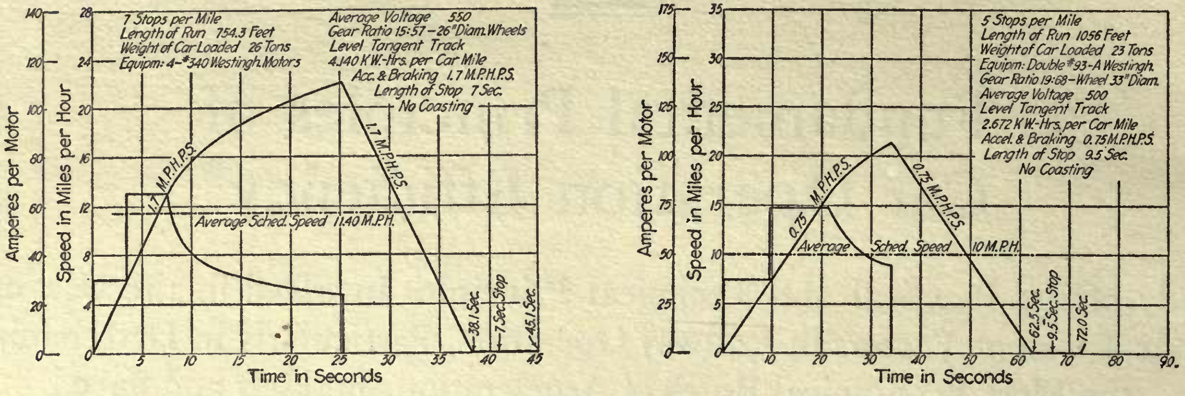
[3] The average number of stops per mile.

---

*Reprinted by permission from ELECTRIC RAILWAY JOURNAL, Jan. 15, 1916.

Company A

Company B

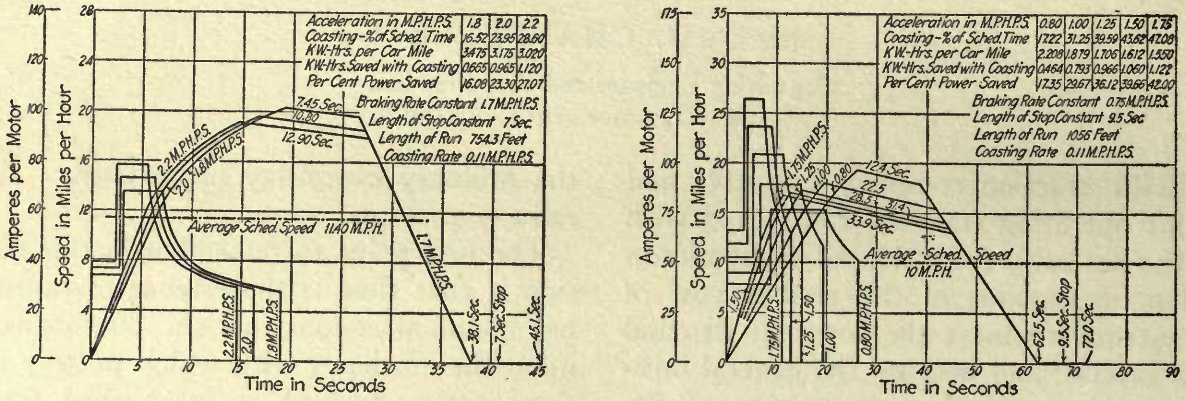


7 Stops per Mile
Length of Run 754.3 Feet
Weight of Car Loaded 26 Tons
Equipm: 4-#340 Westingh. Motors
Average Voltage 550
Gear Ratio 15:57 – 26" Diam. Wheels
Level Tangent Track
4.140 K.W.-Hrs. per Car Mile
Acc. & Braking 1.7 M.P.H.P.S.
Length of Stop 7 Sec.
No Coasting

5 Stops per Mile
Length of Run 1056 Feet
Weight of Car Loaded 23 Tons
Equipm: Double #93-A Westingh.
Gear Ratio 19:68 – Wheel 33" Diam.
Average Voltage 500
Level Tangent Track
2.672 K.W.-Hrs. per Car Mile
Accel. & Braking 0.75 M.P.H.P.S.
Length of Stop 9.5 Sec.
No Coasting

Figure 1

Speed-Time and Power-Time Graphs for No-Coasting Conditions



Acceleration in M.P.H.P.S.	1.8	2.0	2.2
Coasting-% of Sched. Time	16.52	23.95	28.60
K.W.-Hrs. per Car Mile	3.475	3.175	3.020
K.W.-Hrs. Saved with Coasting	0.665	0.965	1.120
Per Cent Power Saved	16.08	23.30	27.07

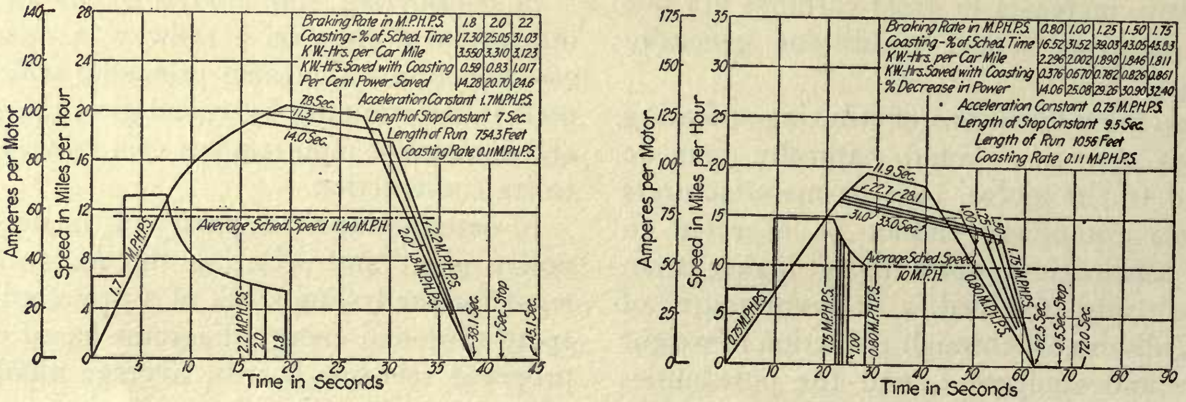
Braking Rate Constant 1.7 M.P.H.P.S.
Length of Stop Constant 7 Sec.
Length of Run 754.3 Feet
Coasting Rate 0.11 M.P.H.P.S.

Acceleration in M.P.H.P.S.	0.80	1.00	1.25	1.50	1.75
Coasting-% of Sched. Time	17.22	31.25	39.59	43.62	47.08
K.W.-Hrs. per Car Mile	2.208	1.879	1.706	1.612	1.550
K.W.-Hrs. Saved with Coasting	0.464	0.793	0.966	1.060	1.122
Per Cent Power Saved	17.35	29.67	36.12	39.66	42.00

Braking Rate Constant 0.75 M.P.H.P.S.
Length of Stop Constant 9.5 Sec.
Length of Run 1056 Feet
Coasting Rate 0.11 M.P.H.P.S.

Figure 2

Speed-Time and Power-Time Graphs for Several Rates of Acceleration



Braking Rate in M.P.H.P.S.	1.8	2.0	22
Coasting-% of Sched. Time	17.30	25.05	31.03
K.W.-Hrs. per Car Mile	3.550	3.310	3.123
K.W.-Hrs. Saved with Coasting	0.59	0.83	1.017
Per Cent Power Saved	14.28	20.70	24.6

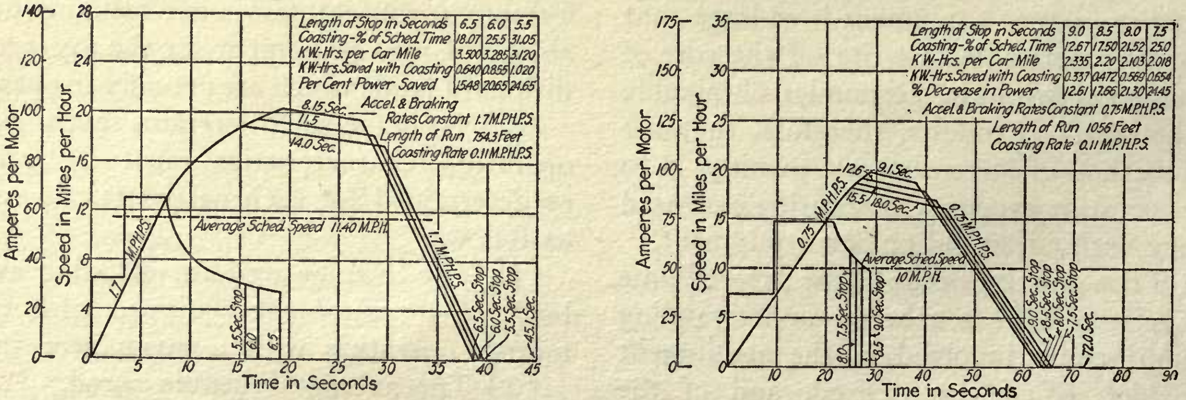
Acceleration Constant 1.7 M.P.H.P.S.
Length of Stop Constant 7 Sec.
Length of Run 754.3 Feet
Coasting Rate 0.11 M.P.H.P.S.

Braking Rate in M.P.H.P.S.	0.80	1.00	1.25	1.50	1.75
Coasting-% of Sched. Time	16.52	31.52	39.03	43.05	45.83
K.W.-Hrs. per Car Mile	2.296	2.002	1.890	1.846	1.811
K.W.-Hrs. Saved with Coasting	0.376	0.670	0.782	0.826	0.861
% Decrease in Power	14.06	25.08	29.26	30.90	32.40

Acceleration Constant 0.75 M.P.H.P.S.
Length of Stop Constant 9.5 Sec.
Length of Run 1056 Feet
Coasting Rate 0.11 M.P.H.P.S.

Figure 3

Speed-Time and Power-Time Graphs for Several Rates of Braking



Length of Stop in Seconds	6.5	6.0	5.5
Coasting-% of Sched. Time	18.07	25.5	31.05
K.W.-Hrs. per Car Mile	3.500	3.285	3.120
K.W.-Hrs. Saved with Coasting	0.640	0.855	1.020
Per Cent Power Saved	15.48	20.65	24.65

Accel. & Braking Rates Constant 1.7 M.P.H.P.S.
Length of Run 754.3 Feet
Coasting Rate 0.11 M.P.H.P.S.

Length of Stop in Seconds	9.0	8.5	8.0	7.5
Coasting-% of Sched. Time	12.67	17.50	21.52	25.0
K.W.-Hrs. per Car Mile	2.335	2.20	2.103	2.018
K.W.-Hrs. Saved with Coasting	0.337	0.472	0.569	0.654
% Decrease in Power	12.61	17.66	21.30	24.45

Accel. & Braking Rates Constant 0.75 M.P.H.P.S.
Length of Run 1056 Feet
Coasting Rate 0.11 M.P.H.P.S.

Figure 4

Speed-Time and Power-Time Graphs for Several Durations of Stop

[4] The average length of a run, that is, 5280 ft. divided by the number of stops per mile.

[5] The average schedule time of a run, that is, the time required to cover the average length of a run at the average schedule speed, including the time consumed in making the average stop.

[6] The average trolley-wire voltage.

[7] The average gradient and degree of curvature of line.

With the above data in hand for two typical roads, designated herein respectively as Company A and Company B, the accompanying sets of diagrams have been prepared to show the inter-relations of the quantities which affect economical car operation. The studies have been made for level and tangent track, but the several factors shown will remain in the same relative proportions if modified to meet the condition of average gradient and degree of curvature. Each study embraces a series of sixteen diagrams and these have been reproduced in such a way as to permit ready comparison.

Each study begins with the "no-coasting" conditions for the case in hand. These comprise the minimum equal rates of "straight line" acceleration and of braking which will enable the car to cover the required distance in the length of time corresponding to the average schedule speed. The straight-line acceleration is that which is determined by the rate of cutting out the starting resistance. After the starting resistance is all cut out the car continues to accelerate at a constantly reducing rate as the motor counter electromotive force rises. For the no-coasting there is a definite energy consumption, which can be readily calculated from the voltage, current and duration of the "power on" period.

Fig. 1, Company A case, shows the no-coasting conditions for a 754.3-ft. run under conditions existing in that city, while Fig. 1, Company B case, shows the no-coasting conditions for a 1056-ft. run. In the first case, 4.14 kilowatt-hours per car-mile are required for a 26-ton car making a schedule speed of 11.4 miles per hour with seven stops per mile. To do this without coasting requires 1.7 miles per hour per second as the rate of acceleration and of braking. The length of stop is seven seconds. In Company B case the energy consumption is 2.672 kilowatt-hours per car-mile for a schedule speed of 10 miles per hour with a 23-ton car, five stops per mile and a stop of nine and one-half seconds' duration. A lower rate of acceleration and braking, 0.75 miles per hour per second is all that is required for no-coasting conditions in this case.

Factors Affecting Energy Input

Before attempting to analyze the diagrams based upon those for no-coasting conditions, it should be noted that the energy input required to operate a car of given weight and equipment, of given gear ratio, at a given average schedule speed with a given average number of stops per mile and a given average trolley voltage is affected solely by the following factors: The duration of acceleration, the duration of braking, and the duration of stops. It will be noted that all of these are time-element factors. The effects of the variations in these elements are illustrated in Figs. 1 to 6, in the Company A and Company B diagrams.

Fig. 1 has already been explained. Fig. 2 shows how coasting can be increased and power saved by increasing the rate and decreasing the duration of acceleration. Fig. 3 shows how similar results can be produced by increasing the rate of braking. Fig. 4 shows how slight decreases in the duration of stop permit increased coasting and decreased power consumption. The results illustrated in the preceding figures are exhibited in Fig. 5 in convenient form for study and show the relation of per cent coasting to per cent energy saving by the three individual methods of saving energy, that is, increasing the rate of acceleration, increasing the rate of braking and decreasing the duration of stops. The average ratio of per cent coasting to per cent energy saving, that is, the saving which could be expected from suitable combinations of these three factors, is also indicated in Fig. 5. This curve might be termed the "coasting characteristic" for this particular case. The results of combining all of the factors which contribute to energy saving are illustrated in Fig. 6.

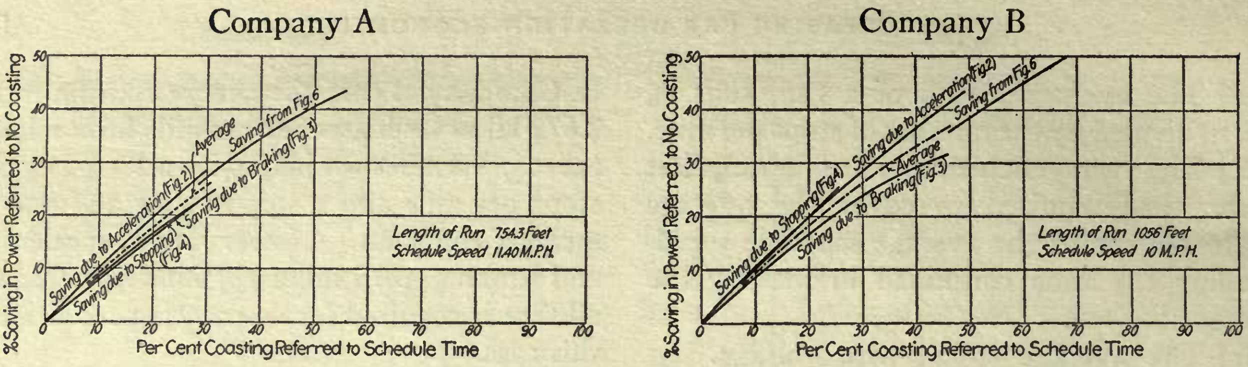
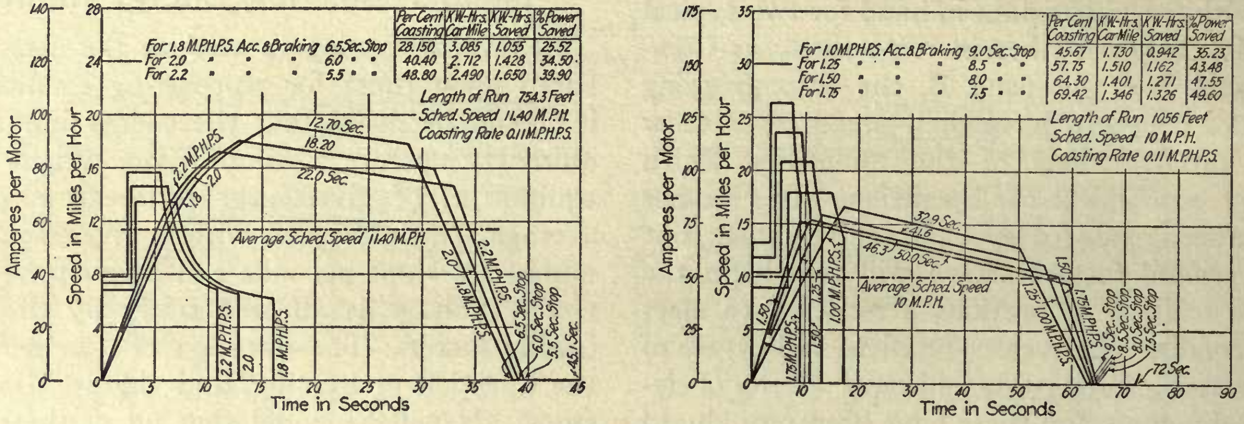


Figure 5

Curves Showing the Relation of Power Saving to Per Cent Coasting



	Per Cent Coasting	K.W.-Hrs. Car Mile	K.W.-Hrs. Saved	% Power Saved
For 1.8 M.P.H.P.S. Acc. & Braking 6.5 Sec. Stop	28.150	3.085	1.055	25.52
For 2.0 " " " 6.0 " "	40.40	2.712	1.428	34.50
For 2.2 " " " 5.5 " "	48.80	2.490	1.650	39.90

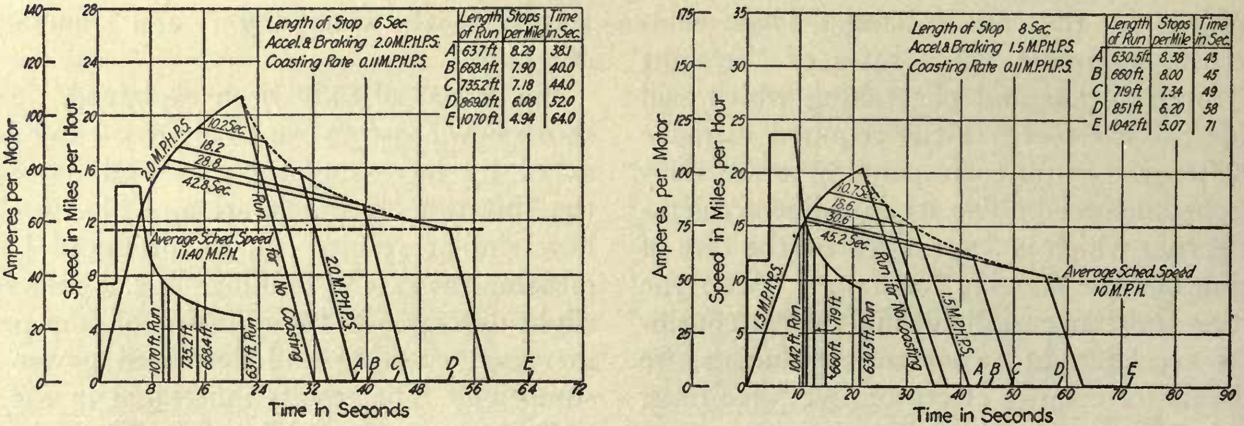
Length of Run 754.3 Feet
Sched. Speed 11.40 M.P.H.
Coasting Rate 0.11 M.P.H.P.S.

	Per Cent Coasting	K.W.-Hrs. Car Mile	K.W.-Hrs. Saved	% Power Saved
For 1.0 M.P.H.P.S. Acc. & Braking 9.0 Sec. Stop	45.67	1.730	0.942	35.23
For 1.25 " " " 8.5 " "	57.75	1.510	1.162	43.48
For 1.50 " " " 8.0 " "	64.30	1.401	1.271	47.55
For 1.75 " " " 7.5 " "	69.42	1.346	1.326	49.60

Length of Run 1056 Feet
Sched. Speed 10 M.P.H.
Coasting Rate 0.11 M.P.H.P.S.

Figure 6

Speed-Time and Power-Time Graphs for Several Rates of Acceleration and Braking and Durations of Stop



Length of Stop 6 Sec.
Accel. & Braking 2.0 M.P.H.P.S.
Coasting Rate 0.11 M.P.H.P.S.

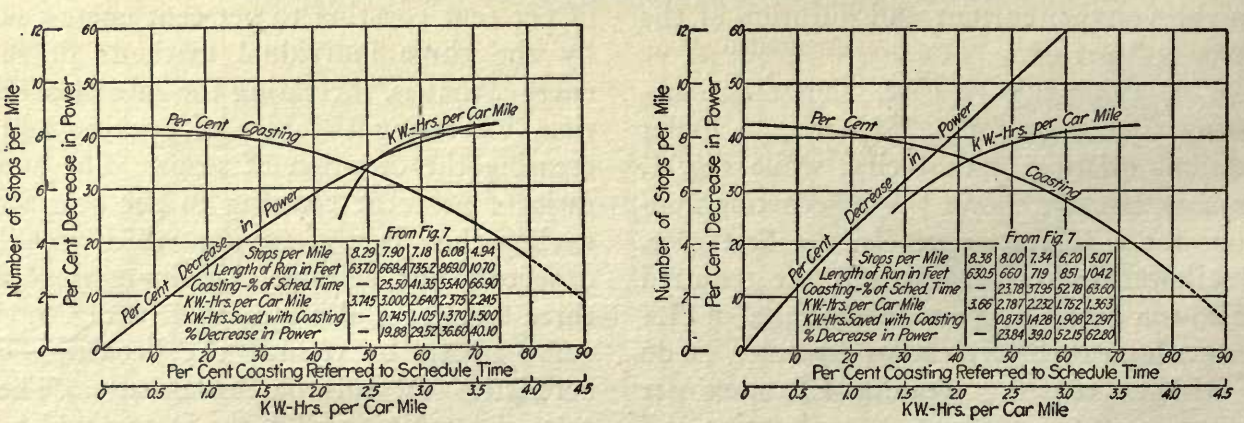
	Length of Run	Stops per Mile	Time in Sec.
A	637 ft.	8.29	38.1
B	668.4 ft.	7.90	40.0
C	735.2 ft.	7.18	44.0
D	869.0 ft.	6.08	52.0
E	1070 ft.	4.94	64.0

Length of Stop 8 Sec.
Accel. & Braking 1.5 M.P.H.P.S.
Coasting Rate 0.11 M.P.H.P.S.

	Length of Run	Stops per Mile	Time in Sec.
A	630.5 ft.	8.38	43
B	660 ft.	8.00	45
C	719 ft.	7.34	49
D	851 ft.	6.20	58
E	1042 ft.	5.07	71

Figure 7

Speed-Time and Power-Time Graphs for Several Numbers of Stops Per Mile



From Fig. 7

Stops per Mile	8.29	7.90	7.18	6.08	4.94
Length of Run in Feet	637.0	668.4	735.2	869.0	1070
Coasting-% of Sched. Time	—	25.50	41.35	55.40	66.90
K.W.-Hrs. per Car Mile	3.745	3.000	2.640	2.375	2.245
K.W.-Hrs. Saved with Coasting	—	0.745	1.105	1.370	1.500
% Decrease in Power	—	19.88	29.52	36.60	40.10

From Fig. 7

Stops per Mile	8.38	8.00	7.34	6.20	5.07
Length of Run in Feet	630.5	660	719	851	1042
Coasting-% of Sched. Time	—	23.78	37.95	52.78	63.60
K.W.-Hrs. per Car Mile	3.66	2.787	2.232	1.752	1.363
K.W.-Hrs. Saved with Coasting	—	0.873	1.428	1.908	2.297
% Decrease in Power	—	23.84	39.0	52.15	62.80

Figure 8

Curves Showing Relation of Stops Per Mile to Energy Consumption and per Cent Coasting, and Per Cent Coasting to Power Saving

A study of the diagrams mentioned above demonstrates the following as the effects of variation in these time-element factors of acceleration, braking and duration of stop on the power input:

[1] The maximum energy input and maximum speed occur when these factors are such as to permit "no-coasting time."

[2] The energy input and the maximum speed both decrease as the time of acceleration is decreased, that is, as the rate of acceleration is increased. Obviously the limitation for the rate of acceleration, within limits of motor equipment, are the slipping of the wheels on the one hand and the comfort of the passengers on the other. In practice the discomfort of the passengers results more from irregularity than rapidity of acceleration.

[3] The energy input and the maximum speed attained both decrease as the time of braking is decreased, that is, as the rate of braking is increased. The limitations of braking are the skidding of the wheels and the comfort of the passengers. Here also the discomfort of the passengers results more from irregular than rapid braking.

[4] The energy input and maximum speed attained both decrease as the time consumed in the stop is decreased. The practical limitation for energy saving at this point depends upon the facilities for boarding and alighting, the alertness of the conductor as to signals and the alacrity of the motorman in obeying or in even anticipating such signals.

Relation of Energy Input to Coasting Time

A most important conclusion from the studies up to this point, deduced from the data shown in Fig. 5, is that as the time-element factors of acceleration, braking and duration of stop, are varied, the corresponding energy consumption is in inverse proportion to the coasting time. These time-element factors solely and only can affect the energy input required to operate a given car and its equipment for given conditions of schedule speed, with an average number of stops per mile, etc.

Up to this point the number of stops per mile has been taken as constant. The next step is to consider the practical conditions arising from a change in this quantity. Figs. 7 and 8 of both Company A and Company B diagrams, have been prepared to show these effects. The no-coasting conditions have been changed so as to permit the original schedule speeds to be maintained with somewhat more than eight stops per mile in each case. In the Company A case this proved to be 2 miles per hour per second and in the Company B case 1½ miles per hour per second for acceleration and braking rates. The results are shown in Fig. 8, in the two sets of diagrams.

Analysis of these results shows that by utilizing the time-element factors of acceleration, braking and duration of stop on any selected basis, the maximum number of stops per mile is obtained with the condition of no-coasting time, with corresponding maximum power input and maximum speed attained. The energy input and maximum speed attained both decrease, and the coasting time increases, as the number of stops per mile is decreased. Another important deduction is that the increased percentage of coasting is practically proportional to the decrease in energy consumed.

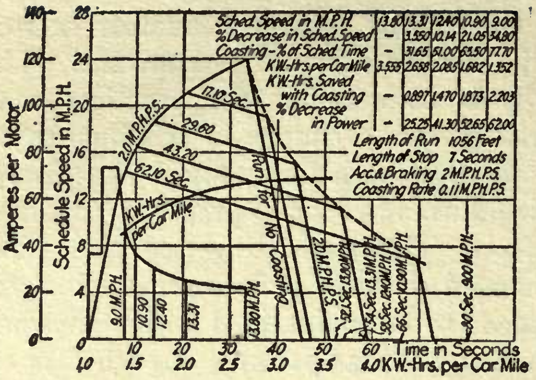
Relation of Schedule Speed to Power and Platform Expense

The next step for consideration is the problem paramount in the minds of executives and transportation managers, namely, that of determining the most efficient schedule speeds. The solution of this problem can be found by the methods previously used. Figs. 9 to 12, in the two series of diagrams, have been prepared to indicate the solution of the problem for the typical cases selected for illustration.

Taking the same no-coasting conditions as in the preceding case but varying the duration of stops so as to give greater values with fewer stops per mile, diagrams have been worked out for typical numbers of stops per mile. The results show that with the time-element factors of acceleration, braking and duration of stop utilized on any selected basis, and a given average number of stops per mile, the

Company A

Company B

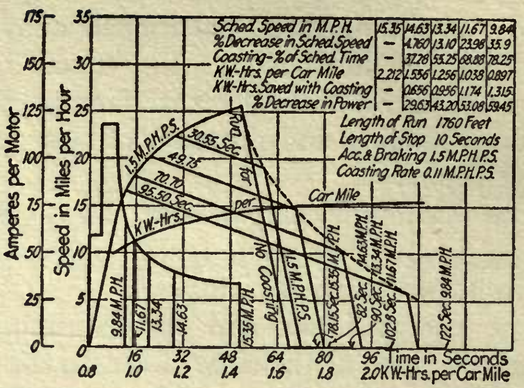


Sched. Speed in M.P.H.	13.80	13.31	12.40	10.90	9.00
% Decrease in Sched. Speed	–	3.550	10.14	21.05	34.80
Coasting-% of Sched. Time	–	31.65	51.00	63.50	77.70
KW.-Hrs. per Car Mile	3.555	2.658	2.085	1.682	1.352
KW.-Hrs. Saved with Coasting	–	0.897	1.470	1.873	2.203
% Decrease in Power	–	25.25	41.30	52.65	62.00

Length of Run 1056 Feet
Length of Stop 7 Seconds
Acc. & Braking 2 M.P.H.P.S.
Coasting Rate 0.11 M.P.H.P.S.

Diagrams Showing Operating Conditions for Several Schedule Speeds, with Five Stops Per Mile

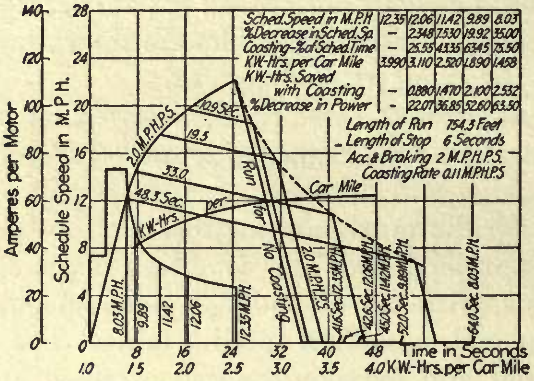
Figure 9



Sched. Speed in M.P.H.	15.35	14.63	13.34	11.67	9.84
% Decrease in Sched. Speed	–	4.760	13.10	23.98	35.9
Coasting-% of Sched. Time	–	37.28	55.25	68.88	78.25
KW.-Hrs. per Car Mile	2.212	1.556	1.256	1.038	0.897
KW.-Hrs. Saved with Coasting	–	0.656	0.956	1.174	1.315
% Decrease in Power	–	29.63	43.20	53.08	59.45

Length of Run 1760 Feet
Length of Stop 10 Seconds
Acc. & Braking 1.5 M.P.H.P.S.
Coasting Rate 0.11 M.P.H.P.S.

Diagrams Showing Operating Conditions for Several Schedule Speeds, with Three Stops Per Mile

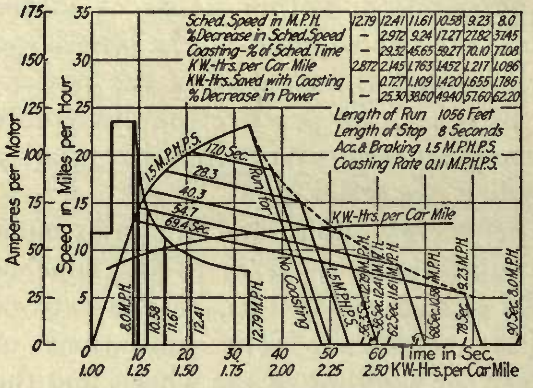


Sched. Speed in M.P.H.	12.35	12.06	11.42	9.89	8.03
% Decrease in Sched. Sp.	–	2.348	7.530	19.92	35.00
Coasting-% of Sched. Time	–	25.55	43.35	63.45	75.50
KW.-Hrs. per Car Mile	3.990	3.110	2.520	1.890	1.458
KW.-Hrs. Saved with Coasting	–	0.880	1.470	2.100	2.532
% Decrease in Power	-	22.07	36.85	52.60	63.50

Length of Run 754.3 Feet
Length of Stop 6 Seconds
Acc. & Braking 2 M.P.H.P.S.
Coasting Rate 0.11 M.P.H.P.S

Diagrams Showing Operating Conditions for Several Schedule Speeds, with Seven Stops Per Mile

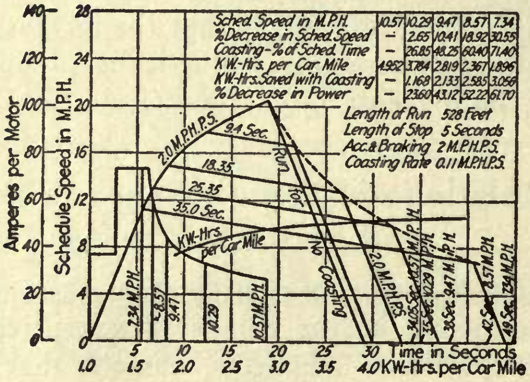
Figure 10



Sched. Speed in M.P.H.	12.79	12.41	11.61	10.58	9.23	8.0
% Decrease in Sched. Speed	–	2.972	9.24	17.27	27.82	37.45
Coasting-% of Sched. Time	–	29.32	45.65	59.27	70.10	77.08
KW.-Hrs. per Car Mile	2.872	2.145	1.763	1.452	1.217	1.086
KW.-Hrs. Saved with Coasting	–	0.727	1.109	1.420	1.655	1.786
% Decrease in Power	–	25.30	38.60	49.40	57.60	62.20

Length of Run 1056 Feet
Length of Stop 8 Seconds
Acc. & Braking 1.5 M.P.H.P.S.
Coasting Rate 0.11 M.P.H.P.S.

Diagrams Showing Operating Conditions for Several Schedule Speeds, with Five Stops Per Mile

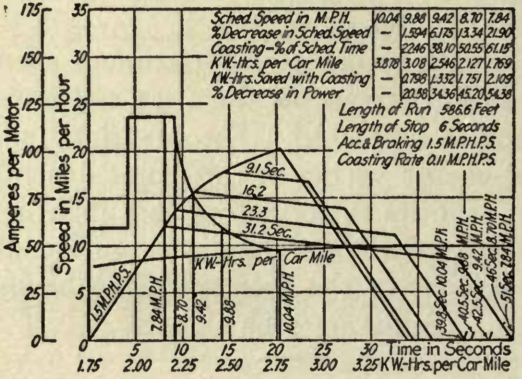


Sched. Speed in M.P.H.	10.57	10.29	9.47	8.57	7.34
% Decrease in Sched. Speed	–	2.65	10.41	18.92	30.55
Coasting-% of Sched. Time	–	26.85	48.25	60.40	71.40
KW.-Hrs. per Car Mile	4.952	3.784	2.819	2.367	1.896
KW.-Hrs. Saved with Coasting	–	1.168	2.133	2.585	3.056
% Decrease in Power	–	23.60	43.12	52.22	61.70

Length of Run 528 Feet
Length of Stop 5 Seconds
Acc. & Braking 2 M.P.H.P.S.
Coasting Rate 0.11 M.P.H.P.S.

Diagrams Showing Operating Conditions for Several Schedule Speeds, with Nine Stops Per Mile

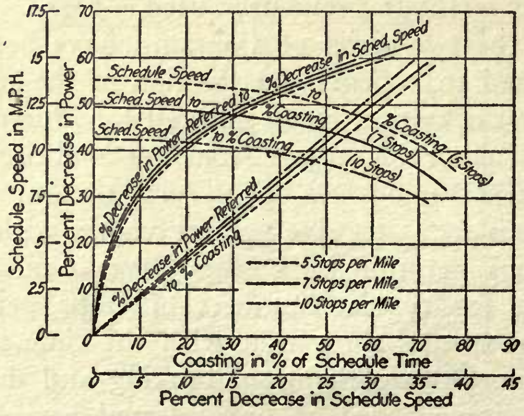
Figure 11



Sched. Speed in M.P.H.	10.04	9.88	9.42	8.70	7.84
% Decrease in Sched. Speed	–	1.594	6.175	13.34	21.90
Coasting-% of Sched. Time	–	22.46	38.10	50.55	61.15
KW.-Hrs. per Car Mile	3.878	3.08	2.546	2.127	1.769
KW.-Hrs. Saved with Coasting	–	0.798	1.332	1.751	2.109
% Decrease in Power	–	20.58	34.36	45.20	54.38

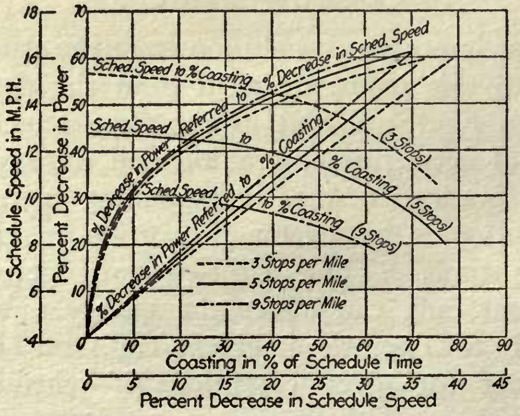
Length of Run 586.6 Feet
Length of Stop 6 Seconds
Acc. & Braking 1.5 M.P.H.P.S.
Coasting Rate 0.11 M.P.H.P.S.

Diagrams Showing Operating Conditions for Several Schedule Speeds, with Ten Stops Per Mile



Curves Showing Operating Conditions Compared with No-Coasting Conditions with Five, Seven and Ten Stops Per Mile

Figure 12



Curves Showing Operating Conditions Compared with No-Coasting Conditions with Three, Five and Nine Stops Per Mile

maximum schedule speed is obtained with no-coasting time, and with corresponding maximum energy input.

The diagrams show further that energy input decreases and coasting time increases as the schedule speed decreases, and that the per cent decrease in energy input is in proportion to the increase in per cent coasting. It should be noted, however, that the curves plotted for per cent decrease in energy-input referred to per cent decrease in schedule speeds rise very rapidly, particularly at low values of these quantities. In considering an increase in schedule speeds, therefore, we must balance the increased cost of energy with the decreased cost of platform labor.

Figs. 13 to 15 in Company A and Company B diagrams have been prepared to show the relation of energy consumption in kilowatt-hours per car-mile to per cent coasting and to schedule speeds; the relation of total energy and platform expense to schedule speeds and the relation of total energy and platform expense to the per cent coasting.

The curves shown in these figures were plotted from data tabulated in the accompanying tables III, IV, V, VI, VII and VIII.

Coasting as a Necessary Factor in Economy

Figs. 13 to 15 summarize all that has gone before on a cost basis. It is obvious that a certain amount of coasting is necessary in any schedule. For any existing or adopted schedule speed, additional coasting can only mean increased efficiency under such schedule. It is apparent, however, that for given car equipment, dependent upon traffic conditions, there is a most economical schedule speed with its corresponding per cent coasting resulting. The method for the solution of this problem is shown clearly in the curves.

Fig. 13 contains curves which form a summary of the data in the preceding four figures in each set of diagrams, and they show definitely the relation of energy consumption to per cent coasting and schedule speed respectively for three numbers of stops per mile. By combining with this information the cost of energy and platform labor for the case in hand it is possible to put the study upon a cost basis.

In Fig. 14 two sets of operating cost curves are plotted, one with costs plotted against schedule speeds and the other with costs plotted against per cent coasting. These are shown on the basis of 0.75 cent per kilowatt-hour energy cost, and 54 cents per hour platform labor cost in one case and 0.7 cent and 60 cents, respectively, in the other. In each curve there is a minimum value which is obviously the best one for the given number of stops per mile. In order to emphasize these minimum cost values, curves are drawn through the minimum values of the two sets of curves respectively.

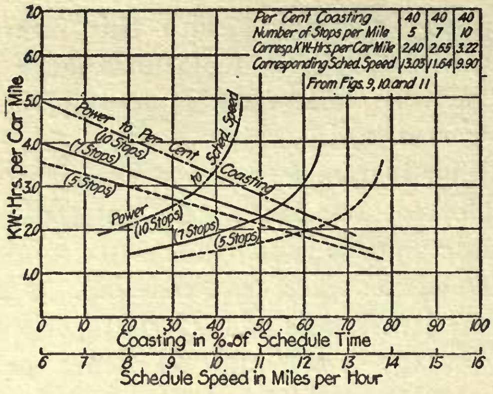
In Fig. 15 the same data are plotted so that the most economical schedule speed can be read directly for any desired number of stops per mile and the corresponding per cent of coasting, combined power and platform labor cost and energy consumption are shown by curves plotted against number of stops per mile.

Both Fig. 14 and 15 show that when the schedule speeds are determined with relation to economical results, coasting must result and that the amount of coasting which corresponds to the most economical schedule speed is approximately the same in per cent over a wide range in the number of stops per mile.

Energy Input a Misleading Measure of Efficiency

Referring to Fig. 13 of Company A diagrams we note that for 40 per cent coasting with five stops per mile the energy input is 2.4 kilowatt-hours per car-mile, with a schedule speed of 13 miles per hour. For 40 per cent coasting with seven stops per mile the energy input is 2.65 kilowatt-hours per car-mile with a schedule speed of 11.64 miles per hour. For 40 per cent coasting with ten stops per mile, the energy input is 3.21 kilowatt-hours per car-mile with a schedule speed of 9.94 miles per hour. Now the number of stops per mile selected for illustration, with the corresponding schedule speeds,

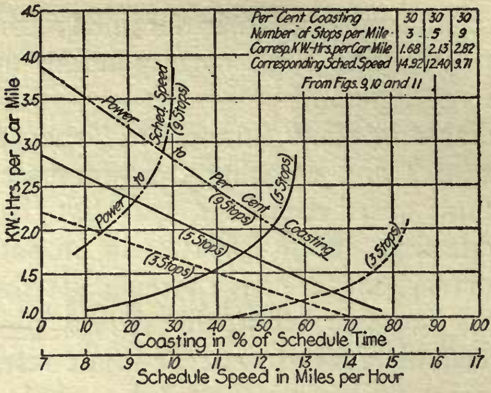
Company A



Per Cent Coasting	40	40	40
Number of Stops per Mile	5	7	10
Corresp. K.W.-Hrs. per Car Mile	2.40	2.65	3.22
Corresponding Sched. Speed	13.05	11.64	9.90

From Figs. 9, 10 and 11

Company B



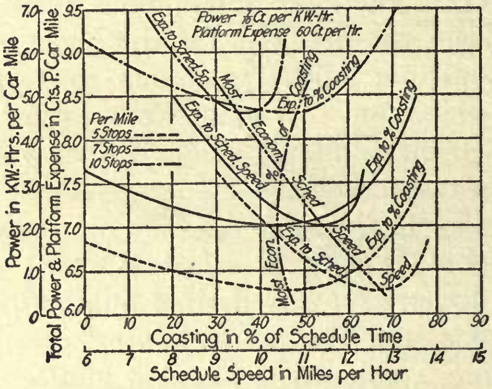
Per Cent Coasting	30	30	30
Number of Stops per Mile	3	5	9
Corresp. K.W.-Hrs. per Car Mile	1.68	2.13	2.82
Corresponding Sched. Speed	14.92	12.40	9.71

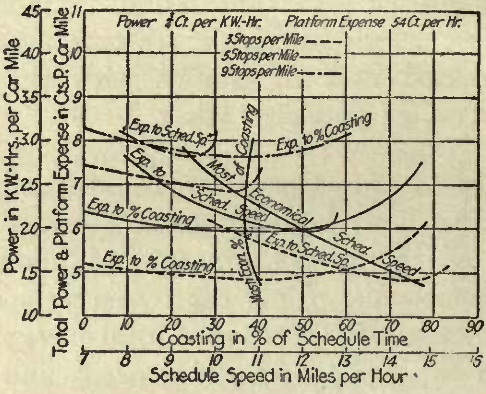
From Figs. 9, 10 and 11

Curves Showing the Relation of Power to Schedule Speed and Per Cent Coasting for Five, Seven and Ten Stops Per Mile

Figure 13

Curves Showing the Relation of Power to Schedule Speed and Per Cent Coasting for Three, Five and Nine Stops Per Mile





Curves Showing the Relation of Power and Platform Expense to Per Cent Coasting and Schedule Speed, for Five, Seven and Ten Stops Per Mile

Figure 14

Curves Showing the Relation of Power and Platform Expense to Per Cent Coasting and Schedule Speed, for Three, Five and Nine Stops Per Mile

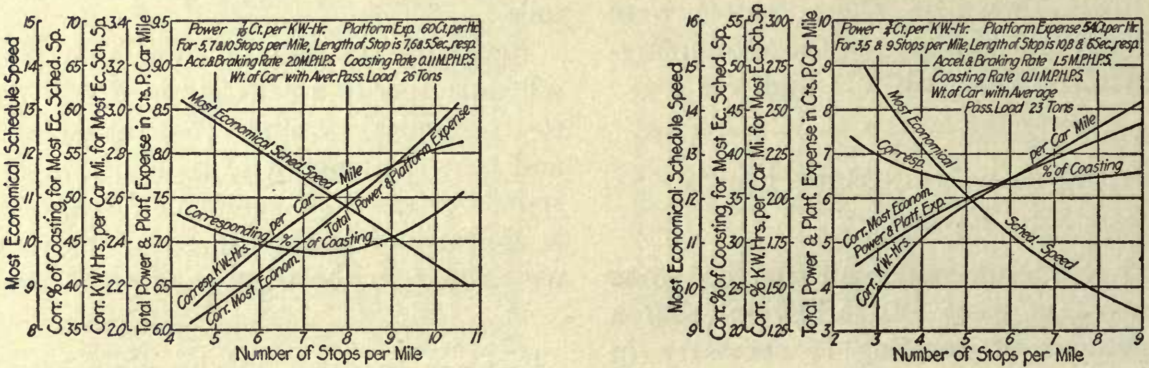


Figure 15

Curves Showing the Most Economical Schedule Speed and Corresponding Cost and Energy Consumption for Different Numbers of Stops Per Mile

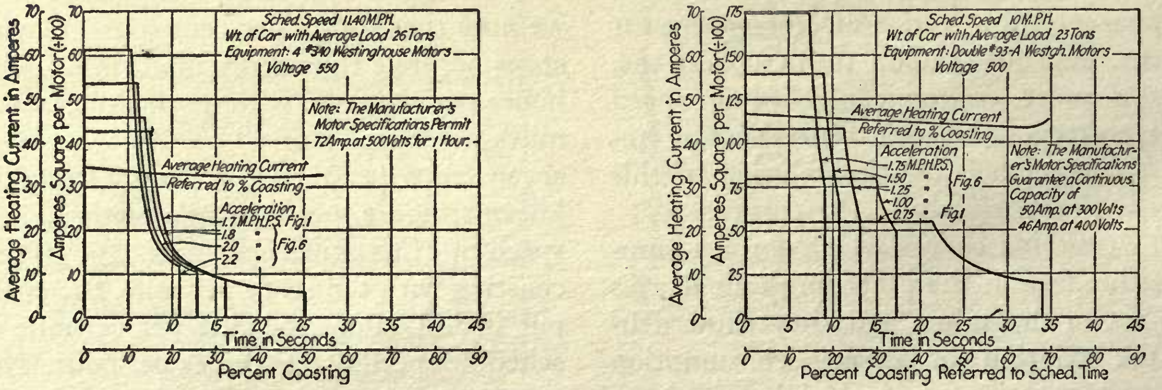


Figure 16

Diagrams of Heating Currents Corresponding to Different Operating Conditions Shown in Fig. 6

are representative of the range in these quantities actually encountered for varying densities of non-rush-hour and rush-hour conditions.

For the above enumerated stops per mile and corresponding schedule speeds, motormen showing coasting records of 40 per cent on that equipment are all operating at equal actual efficiency, even though the conditions of operation vary widely, as enumerated. The coasting record of the motorman, therefore, is the correct relative measure of his actual efficiency for variations in the number of stops per mile or in the schedule speed that must necessarily arise in practical operation.

On the other hand, the measurement of only the energy input of the car is an incorrect and misleading measure of the motorman's actual efficiency where the number and duration of stops or schedule speeds are variable. Efficiency based on such power measurement means nothing unless analyzed in reference to the component time-element factors controlling the energy-input, for as we have noted in the illustrations (opposite), this may vary from 2.4 kilowatt-hours to 3.21 kilowatt-hours per car-mile, although the true efficiency of the motorman is exactly the same.

The incorrectness of conclusions based upon energy measurements where the number and duration of stops are variable is further illustrated by reference to Figs. 4 and 8 of Company B diagrams. In Fig. 4, with 10 miles per hour schedule speed, five stops per mile of eight seconds' duration each, and acceleration and braking respectively ¾ miles per hour per second, the per cent coasting is seen to be 21½ and the energy input 2.1 kilowatt-hours per car-mile. In Fig. 8 with the same schedule speed, 7.18 stops per mile of the same duration and twice the rate of acceleration and braking, the per cent coasting is seen to be 42 and the energy input 2.1 kilowatt-hours per car-mile.

Based on power input measurement the performance of the motormen is exactly the same in the two cases, yet everyone knows that the additional stops in the second case require additional energy. By the efficient utilization of the time-element factors of acceleration and braking the motorman in the second case used the same energy input as did the one in the first case, but the percentage of coasting resulting was approximately double, even with additional stops. Had the motorman in the first case used 1½ miles per hour per second acceleration and braking, as was done in the second case, the percentage of coasting would have been 64.3 and the energy input 1.4 kilowatt-hours per car-mile.

Coasting the Correct Relative Measure of Actual Efficiency

The actual efficiency, based upon the inherent principles involved in operating any given car under given conditions, is dependent upon the effective utilization of the controlling time-element factors.

For further better understanding of the factors affecting the motorman's actual efficiency Fig. 17 has been prepared, showing speed-time and power diagrams, for common variations encountered under the simplest conditions of operation, i.e., a constant schedule speed, with assumed equal duration of stops for the average number of stops per mile. In Fig. 17, seven typical runs, numbered 1 to 7, are shown, the number of stops per mile being either five, six or seven and, as indicated, each stop being of eight seconds' duration.

It is to be noted from Fig. 17 that, for like number of stops per mile, the per cent coasting increases and the power input decreases, dependent upon the increase in acceleration and

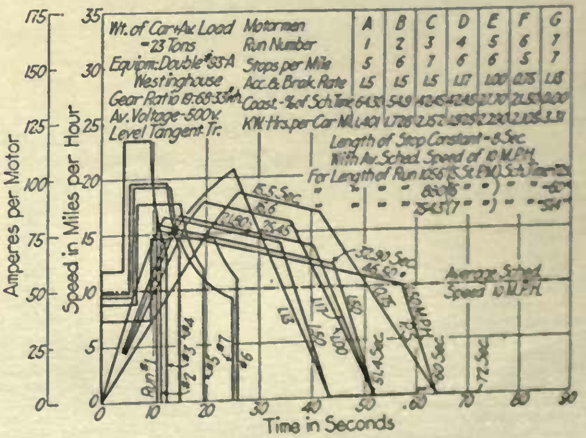


Figure 17

Speed-Time and Power Graphs for Five, Six and Seven Stops per Mile for Several Rates of Acceleration and Braking at Constant Schedule Speed

Tables III to VIII—Analysis of Relation of Energy and Platform Expense

Based on variable schedule speed with efficient coasting, determined from time-speed and energy diagrams. Track level and tangent

Company A—Motor Car Without Trailer

Weight with average load, tons	26
Gear ratio	15:57
Line voltage	550
Wheel diameter, inches	26
Rate of acceleration and braking, m.p.h.p.s	2
Energy cost, cent per kilowatt-hour	0.7
Platform labor cost, cents per hour	60

Table III

Stops per mile.. 5
Duration of stop, seconds.................................... 7

Schedule Speed, Miles per Hour	Per Cent of Coasting Possible	Kilowatt-Hours per Car-Mile	Cost of Power per Car-Mile, Cents	Platform Expense per Car-Mile, Cents	Combined Power and Platform Expense per Car-Mile, Cents
9.00	77.70	1.35	0.95	6.67	7.62
10.90	65.60	1.68	1.18	5.50	6.68
12.40	51.00	2.08	1.46	4.84	6.30
13.31	31.65	2.66	1.86	4.51	6.37
13.80	None	3.53	2.47	4.35	6.82

With 13.80 m.p.h. schedule speed, total energy per car-hour is...48.71 kw.-hr.
With 12.40 m.p.h. schedule speed, total energy per car-hour is...25.79 kw.-hr.
Excess power per car-hour for 13.80 m.p.h. over 12.40 m.p.h. is...22.92 kw.-hr.
Or excess power for 13.80 m.p.h. over energy for 12.40 m.p.h. is...88.8 per cent
But 13.80 m.p.h. schedule speed in excess of 12.40 m.p.h. is......11.3 per cent
Nine cars at 13.80 m.p.h. make 124.20 car-miles, using..438.39 kw.-hr. per hour
Ten cars at 12.40 m.p.h. make 124.00 car-miles, using...257.90 kw.-hr. per hour
Saving in kilowatt-hour output per hour for ten cars at 12.40 m.p.h. over nine cars at 13.80 m.p.h. schedule speed, both making approximately the same car-miles and hence running on the same headway, is..........180.49 kw.-hr. per hour
Or as offset to investment for one additional car there is required an investment for 180 kw. in power plant and distribution system.

Table IV

Stops per mile.. 7
Duration of stop, seconds.................................... 6

Schedule Speed, Miles per Hour	Per Cent of Coasting Possible	Kilowatt-Hours per Car-Mile	Cost of Power per Car-Mile, Cents	Platform Expense per Car-Mile, Cents	Combined Power and Platform Expense per Car-Mile, Cents
8.03	75.50	1.46	1.02	7.47	8.49
9.89	63.45	1.89	1.32	6.07	7.39
11.42	43.35	2.52	1.76	5.25	7.01
12.06	25.55	3.11	2.18	4.97	7.15
12.35	None	3.99	2.79	4.86	7.65

With 12.35 m.p.h. schedule speed, total power per car-hour is....49.27 kw.-hr.
With 11.42 m.p.h. schedule speed, total power per car-hour is....28.78 kw.-hr.
Excess power per car-hour for 12.35 m.p.h. over 11.42 m.p.h. is...20.49 kw.-hr.
Or excess power for 12.35 m.p.h. over power for 11.42 m.p.h. is...71.2 per cent
But 12.35 m.p.h. schedule speed in excess of 11.42 m.p.h. is........ 8.1 per cent
Ten cars at 12.35 m.p.h. gives 123.5 car-miles using....492.76 kw.-hr. per hour
Eleven cars at 11.42 m.p.h. gives 125.6 car-miles using.316.56 kw.-hr. per hour
Saving in kilowatt-hour output per hour for eleven cars at 11.42 m.p.h. over ten cars at 12.35 m.p.h., schedule speed, both making approximately the same car-miles and hence running on the same headway is....176.20 kw.-hr. per hour
Or as offset to investment for one additional car there is required an investment for 176 kw. in power plant and distribution system.

Table V

Stops per mile.. 10
Duration of stop, seconds.................................... 5

Schedule Speed, Miles per Hour	Per Cent of Coasting Possible	Kilowatt-Hours per Car-Mile	Cost of Power per Car-Mile, Cents	Platform Expense per Car-Mile, Cents	Combined Power and Platform Expense per Car-Mile, Cents
7.34	71.40	1.90	1.33	8.17	9.50
8.57	60.40	2.37	1.66	7.00	8.66
9.47	48.25	2.82	1.97	6.34	8.31
10.29	26.85	3.78	2.65	5.83	8.48
10.57	None	4.95	3.47	5.68	9.15

With 10.57 m.p.h. schedule speed, total power per car-hour is...52.32 kw.-hr.
With 9.47 m.p.h. schedule speed, total power per car-hour is...26.70 kw.-hr.
Excess power per car-hour for 10.57 m.p.h. over 9.47 m.p.h. is..25.62 kw.-hr.
Or excess power for 10.57 m.p.h. over power for 9.47 m.p.h. is..95.9 per cent
But 10.57 m.p.h. schedule speed in excess of 9.47 m.p.h. is.........11.6 per cent
Nine cars at 10.57 m.p.h. gives 95.13 car-miles using.....470.88 kw.-hr. per hour
Ten cars at 9.47 m.p.h. gives 94.70 car-miles using.......267.10 kw.-hr. per hour
Saving in kilowatt-hours output per hour for ten cars at 9.47 m.p.h. over nine cars at 10.57 m.p.h. schedule speed, both making approximately the same car-miles, and hence running on the same headway is..........203.88 kw.-hr. per hour
Or as offset to investment for one additional car there is required an investment for 203 kw. in power plant and distribution system.

Company B—Motor Car Without Trailer

Weight with average load, tons	23
Gear ratio	19:68
Line voltage	500
Wheel diameter, inches	33
Rate of acceleration and braking, m.p.h.p.s	1.5
Energy cost, cent per kilowatt-hour	0.75
Platform labor cost, cents per hour	54

Table VI

Stops per mile.................... 3 | Duration of stop, seconds.......... 10

Schedule Speed, Miles per Hour	Per Cent of Coasting Possible	Kilowatt-Hours per Car-Mile	Cost of Power per Car-Mile, Cents	Platform Expense per Car-Mile, Cents	Combined Power and Platform Expense per Car-Mile, Cents
9.84	78.25	0.90	0.67	5.49	6.16
11.67	68.88	1.04	0.78	4.63	5.41
13.34	55.25	1.26	0.94	4.05	4.99
14.50	39.88	1.46	1.09	3.72	4.81
14.63	37.28	1.56	1.17	3.69	4.86
15.35	None	2.21	1.66	3.52	5.18

With 15.35 m.p.h. schedule speed, total power per car-hour is...33.92 kw.-hr.
With 14.50 m.p.h. schedule speed, total power per car-hour is...21.17 kw.-hr.
Excess power per car-hour for 15.35 m.p.h. over 14.50 m.p.h. is..12.75 kw.-hr.
Or excess power for 15.35 m.p.h. over power for 14.50 m.p.h. is..60.2 per cent
But 15.35 m.p.h. schedule speed in excess of 14.50 m.p.h. is....... 5.9 per cent
Seventeen cars at 15.35 m.p.h. gives 260.95 car-miles using.................................576.64 kw.-hr. per hour
Eighteen cars at 14.50 m.p.h. gives 261.00 car-miles using.................................381.06 kw.-hr. per hour
Saving in kilowatt-hour output per hour for eighteen cars at 14.50 m.p.h. over seventeen cars at 15.35 m.p.h. schedule speed; both making approximately the same car-miles, and hence running on the same headway, is.............................195.58 kw.-hr. per hour
Or as offset to investment for one additional car there is required an investment for 195 kw. in power plant and distribution system.

Table VII

Stops per mile.................... 5 | Duration of stop, seconds............ 8

Schedule Speed, Miles per Hour	Per Cent of Coasting Possible	Kilowatt-Hours per Car-Mile	Cost of Power per Car-Mile, Cents	Platform Expense per Car-Mile, Cents	Combined Power and Platform Expense per Car-Mile, Cents
8.00	77.08	1.09	0.82	6.75	7.57
9.23	70.10	1.22	0.91	5.85	6.76
10.58	59.27	1.45	1.09	5.10	6.19
11.61	45.65	1.76	1.32	4.65	5.97
12.05	36.80	1.96	1.47	4.48	5.95
12.41	28.32	2.14	1.60	4.35	5.95
12.79	None	2.87	2.15	4.22	6.37

With 12.79 m.p.h. schedule speed, total power per car-hour is...36.71 kw.-hr.
With 12.05 m.p.h. schedule speed, total power per car-hour is...23.62 kw.-hr.
Excess power per car-hour for 12.79 m.p.h. over 12.05 m.p.h. is..13.09 kw.-hr.
Or excess power for 12.79 m.p.h. over power for 12.05 m.p.h. is..55.4 per cent
But 12.79 m.p.h. schedule speed in excess of 12.05 m.p.h. is....... 6.1 per cent
Seventeen cars at 12.79 m.p.h. gives 217.43 car-miles using.................................624.07 kw.-hr. per hour
Eighteen cars at 12.05 m.p.h. gives 216.90 car-miles using.................................425.16 kw.-hr. per hour
Saving in kilowatt-hour output per hour for eighteen cars at 12.05 m.p.h. over seventeen cars at 12.79 m.p.h. schedule speed; both making approximately the same car-miles, and hence running on the same headway, is.............................198.91 kw.-hr. per hour
Or as offset to investment for one additional car there is required an investment for 198 kw. in power plant and distribution system.

Table VIII

Stops per mile.................... 9 | Duration of stop, seconds............6

Schedule Speed, Miles per Hour	Per Cent of Coasting Possible	Kilowatt-Hours per Car-Mile	Cost of Power per Car-Mile, Cents	Platform Expense per Car-Mile, Cents	Combined Power and Platform Expense per Car-Mile, Cents
7.84	61.15	1.77	1.33	6.89	8.22
8.70	50.55	2.13	1.60	6.21	7.81
9.42	37.90	2.55	1.91	5.73	7.64
9.88	22.46	3.08	2.31	5.46	7.77
10.04	None	3.88	2.91	5.38	8.29

With 10.04 m.p.h. schedule speed, total power per car-hour is...38.96 kw.-hr.
With 9.42 m.p.h. schedule speed, total power per car-hour is...24.02 kw.-hr.
Excess power per car-hour for 10.04 m.p.h. over 9.42 m.p.h. is...14.94 kw.-hr.
Or excess power for 10.04 m.p.h. over power for 9.42 m.p.h. is...62.2 per cent
But 10.04 m.p.h. schedule speed in excess of 9.42 m.p.h. is....... 6.6 per cent
Fifteen cars at 10.04 m.p.h. gives 150.60 car-miles using.................................584.40 kw.-hr. per hour
Sixteen cars at 9.42 m.p.h. gives 150.72 car-miles using.384.32 kw.-hr. per hour
Saving in kilowatt-hour output per hour for sixteen cars at 9.42 m.p.h over fifteen cars at 10.04 m.p.h. schedule speed; both making approximately the same car-miles, and hence running on the same headway, is..200.08 kw.-hr. per hour
Or as offset to investment for one additional car there is required an investment for 200 kw. in power plant and distribution system.

braking rates. Now, assume these Runs 1 to 7 are made respectively by motormen A to G. Assume further that, as is the case in practice, nothing is known as to the number of stops per mile, the only known quantity being the schedule speed. Under such conditions suppose the performance of these motormen on their respective runs to be checked, on the one hand, by coasting measurements and, on the other hand, by measurement of the power input. Which method of checking would indicate the correct relative measure of the respective motormen's actual efficiency?

The standing rating of the respective motormen can be stated as follows:

[1] Basis of actual efficiency. Since the best efficiency for each respective number of stops per mile occurs with the highest rates of acceleration and braking, all motormen operating with such highest rates can be rated as "Par" and the remaining motormen rated the "Per cent below par," which the power actually used exceeds in per cent the power which would have been used had the highest, or "Par," rates of acceleration and braking been utilized.

[2] Basis of per cent coasting determined from the measurement of the coasting time.

[3] Basis of power input measured by meter, the motorman using the minimum power input (kilowatt-hours per car mile) being rated as "Par" and the remaining motormen being rated the "Per cent below par" which their respective values of kilowatt-hours per car-mile actually used exceed in per cent the minimum or "Par" value of kilowatt-hours per car mile.

[4] Basis of motorman's index number determined from metered measurements of the power input; each motorman's index number being the ratio of the kilowatt-hours per car mile used by such motorman to the average of the kilowatt-hours per car mile of all the motormen.

Table I shows a tabulation of the rated standings of the several motormen on the respective foregoing basis for ratings.

Table I

TABULATION OF RATED STANDING OF MOTORMEN A TO G, WHOSE OPERATIONS ARE SHOWN BY THE DIAGRAMS OF FIG. 17

1. Basis Actual Efficiency	2. Basis Per Cent Coasting	3. Basis Power Input	4. Basis Index Number
A—Par	A—64.3	A—Par	A—1.520
B—Par	B—54.9	B—23.3 per cent below par	B—1.232
C—Par	C—42.45	D—37.4 per cent below par	D—1.106
D—11.4 per cent below par	D—42.45	F—50.1 per cent below par	F—1.012
E—43.5 per cent below par	E—27.7	C—53.6 per cent below par	C—0.989
F—50.1 per cent below par	F—21.5	E—63.4 per cent below par	E—0.930
G—53.8 per cent below par	G—0	G—136.2 per cent below par	G—0.640

From Table I it is to be noted the rated standing of the respective motormen, based on the per cent coasting, is relatively correct, compared with the rated standing on the basis of actual efficiency; the discrepancies being that though the actual efficiency of motormen A, B and C is the same, the rated standing on the basis of per cent coasting differentiates as shown.

This differentiation is desirable, for results in practical operation show that the motorman tends to accelerate and brake at rates proportioned to the traffic requirements, instead of the efficient rates, unless his operations are effectively checked. From Fig. 17 it is to be noted that the stops per mile for A were less than for B, whose stops in turn were less than those of C. The tendency in practice would have been for B to operate less efficiently than C, and A even less than B in reference to the controlling time-element factors. Therefore, the psychological and practical effect is good if A and B are given credit, in their rated standing, as is done by the per cent coasting rating, for their efficient operation under the easier traffic conditions.

Economic Advantages of the Skip-Stop Plan

The enormous advantages to the public and the railway from the utilization of the skip-stop plan are illustrated by data taken from Figs. 13 to 15 of Company A diagrams for

Table II

SHOWING GAINS BY REDUCTION IN NUMBER OF STOPS

	Ten Stops Per Mile	Seven Stops Per Mile	Per Cent Increase
Most economical schedule speed in m.p.h.	9.48	11.4	20.2
Corresponding total energy and platform cost per car-mile, cents	8.32	7.03	15.5*
Total car-miles per car per year, based on 4000-hr. operation...	37,920	45,600	20.2
Energy and platform labor cost per car per year, basis 4000 hr.	$3,154.92	$3,205.68	1.6

*Decrease.

seven and ten stops per mile. The following table shows the results of eliminating three stops per mile.

Table II shows that the reduction from ten to seven stops per mile results in making available for the public 20.2 per cent more service, with 20.2 per cent saving in time due to increased rapid transit, at an approximate additional cost of only 1.6 per cent to the railway, on the basis of 4000 car-hours operation per car per year.

A similar study of Company B curves shows that, based on 4000 hours of operation per car per year, a reduction from seven to five stops per mile results in 15.7 per cent more available service for the public with 15.7 per cent saving in time, at only 0.7 per cent additional cost.

In concluding this part of the subject, it should be noted that while the curves in Fig. 15 show the most economical schedule speeds for given numbers of stops per mile, together with the corresponding most economical energy and platform expense, based on given energy and platform labor costs and for a given equipment, similar curves can be determined and constructed for any combination of expense rates. The important, dominating principle demonstrated by the curves is that the determination of conditions yielding best economy carry with them such utilization of the time-element factors that coasting time must result.

It would not be right to leave this phase of the subject without considering the effect of variation in the time-element factors upon the heating of the motor equipment. Fig. 16, for Company A and Company B conditions, shows the results of studies made to determine this heating effect. In each case the square of the current, to which the heating is proportional, is plotted against time, and the average heating current is plotted against per cent coasting. The curve between the average heating current and per cent coasting shows that the results already described can be secured without exceeding the equipment limitations.

Questions may also be raised as to the effect of the rheostatic losses on the results and as to the effect of short-period, high-rate acceleration on the power plant. The construction and analysis of speed-time and power diagrams based on the maximum deviation of series operation with maintenance of schedule speeds for any average condition, will dispel any illusion that rheostatic losses may more than offset efficient utilization of the time-element factors hereinbefore discussed.

Reduction in Demand on Generating Station and Distribution System

That the adoption of a high rate of acceleration will not increase the demand on the power plant, substation equipment, etc., follows from the fact that the duration of the acceleration current and the required average current both decrease as the rate of acceleration increases. As the current peaks produced by the different cars occur at different times, when the diversity factor of the usual number of cars operated is considered it is apparent that only the sum of the reduced average currents is drawn from the power plant.

As generating and substation equipment ratings are usually based on hourly output, the average current drawn from, or the "demand" upon such equipment, for the usual rating periods of time, will be reduced approximately by the same percentage as the efficiency is increased by the efficient utilization of the controlling time-element factors, herein discussed. It is further apparent from a study of the several speed-time and power diagrams that the investment for an efficiency checking system will be offset many fold by the value of the generating station, distribution system, and substation capacity, unrequired or available for other purposes, due to the reduction of the demand thereon.

Summary and Conclusions

By way of summarizing and emphasizing the results of the foregoing analysis of efficiency of car operation the following may be of interest

[1] The power input necessary to operate a given car and equipment at a given average schedule speed and with a given number of stops per mile is solely dependent upon the

efficient utilization of the time-element factors: acceleration, braking and duration of stop.

[2] The effect on the power input of variation in these time-element factors is in proportion to the coasting time, and the increase in per cent coasting is in proportion to decrease in per cent energy consumption.

[3] Since efficient utilization of power for given conditions is solely determined by these time-element factors, the correct method of checking the motorman's efficiency in the use of power is by a system giving him a positive, authentic record of his efficient utilization of these factors, which as explained above, is measured by the coasting time and the per cent coasting.

[4] Equipped with such a correct method of checking efficiency, the motorman has only to handle his equipment and to take advantage of physical conditions encountered in operation so as to obtain the greatest possible coasting time, with maintenance of schedule time, on each trip of his run. The coasting time can be increased only by the motorman's efficient utilization of the time-element factors of acceleration, braking and duration of stop, these being the only factors under his control that can affect power input.

[5] The economical schedule speed for given conditions is also dependent upon the efficient utilization of the time-element factors, and to be economical the schedule must be such as to permit of coasting.

[6] The average number of stops per mile, considered in connection with the efficient utilization of the time-element factors, determines the limitations of possible schedule speeds, with a given equipment. It is therefore necessary in determining the economical schedule speed to secure definite data in practical operation of the average number of stops per mile and the average duration thereof.

[7] The per cent coasting is the measure of the correctness of the relation of the controlling time-element factors for any given number of stops per mile and schedule speed, and of the motorman's efficiency without regard to the variation in number of stops per mile and schedule speed encountered in practice.

As was stated earlier in this paper, there is no question as to the necessity for efficiency in operating an electric railway property. Gross earnings can hardly be increased under existing conditions, and, therefore, net earnings can be increased only by the reduction of operating expenses, which is a condition and not a theory that confronts us. In the solution of the problem of securing greater efficiency, practical and technical analysis must be applied to the only factors that control and determine results. As demonstrated hereinbefore, the laws governing these factors are based on known principles, and deductions based on the application of these principles are correct to the certainty of the proverbial "death and taxes."

No railway executive or engineering staff questions the reasonable certainty of obtaining calculated efficiencies and results from the large investment involved in a new power generating station, yet the factors affecting the results obtained from that power station contain many more variables than the time-element factors which control car operation efficiency, and the correct method for checking such efficiency.

Doubtless many operating companies have already secured, or are securing, large economies from increased schedule speeds, from adopting the skip-stop and fixed-stop plans, from the use of coasting signboards, and from education of employees, as a group and by personal instruction, along the line of economies obtainable by proper handling of equipment. All of these activities tend to more efficient utilization of the controlling time-element factors of operation.

The writer realizes the possibilities of such methods, but when the enormous effect of variations of the controlling time-element factors encountered in practical operation is considered, the impossibility of approaching obtainable efficiency without a constant, individual checking record must be apparent.

A check made by means of stop-watch readings of running schedule time, coasting time, average duration of stop and number of stops per mile, will demonstrate the variability in the way in which various motormen utilize the controlling time-element factors under the same conditions, to say nothing of the variations from obtainable possible results, and will prove convincing as to the need for a correct efficiency checking system.

To expect the best obtainable results without such a system is as inconsistent, when the facts involved are considered, as would be the checking of conductors in matters of fares, etc., by the average results per car on the system, instead of using some fare-registering checking system.

The fact that increased economies are accomplished by means of the more or less indirect methods mentioned points unmistakably to the economies which may be obtained when the efficiency problem is approached with the correct tool and accurate yard stick for measuring the efficient utilization of the controlling time-element factors.

It is well recognized that changing the gear ratio or utilizing the principle of field control for motors, will affect material economies under conditions that may be encountered in practical operation. However, it is apparent that such changes will not eliminate the importance for the efficient utilization of the controlling time-element factors herein considered.

It should always be borne in mind that the coasting which has been referred to in this article is that coasting which forms an inherent part of the cycle of operations involved in moving the car efficiently under the practical conditions of traffic operation. Coasting is a function of such a cycle just as is acceleration, braking or duration and number of stops, but, as demonstrated, it is also the measure of the efficient utilization of these factors.

The efficiency checking system based on measurement of coasting comprehends the attainment and measurement of only such coasting as exists as a function of this cycle. It does not involve, as some seem to think, the slowing of schedules, the running by of stopping points, the operation on down grade, etc.

In conclusion the writer believes that executives and transportation managers will agree that the application of practical and technical principles to ordinary, every-day operation is the means for accomplishing efficiency in car operation. When the time-element factors are considered there will be no difference of opinion as to the correct method of checking efficiency, or as to the justification of the necessary investment in the checking system.

Comments on CAR OPERATION EFFICIENCY *by* W. B. POTTER, *Engineer Railway and Traction Department, General Electric Company*

GENERAL ELECTRIC COMPANY
SCHENECTADY, N. Y., *January* 22, 1916.

To the Editors:

I have read with much interest C. C. Chappelle's article in the issue of the ELECTRIC RAILWAY JOURNAL for January 15, on the "Fundamental Principles of Car Operation Efficiency." I quite agree with his argument in favor of the maximum percentage of coasting practicable as an effective method of minimizing the power required for a given run, and that a record of the percentage coasting is a desirable and effective means of determining the relative operating efficiency of different motormen. The percentage values as illustrated by the curves are subject to variation due to condition of track and rolling stock, and I doubt whether results in practice will actually conform with his figures, as a coasting friction of 10 lbs. per ton is lower than usually considered for service of the character illustrated, although modifications on this account would not detract from the general conclusions of the article.

Economy in power, however, is only one of the factors of successful operation. Attempting to secure minimum power possible through maximum obtainable coasting, with acceleration and braking to the limit of adhesion on the rail, would obviously be undesirable as causing discomfort to passengers and increased maintenance by reason of greater wear and tear. There are limits beyond which it will be found undesirable to reduce the power consumption, and it does not follow that the motorman showing the lowest power consumption is necessarily the best operator. Under such circumstances excessive acceleration and braking become as undesirable as the failure to profit by coasting is unnecessary. A proper application of the principles advocated by Mr. Chappelle should result in a marked reduction in the power used by unskillful motormen without in any way causing discomfort to passengers, or adding to maintenance of the equipment.

W. B. POTTER,
Engineer Railway and Traction Department.

Reprinted by permission from ELECTRIC RAILWAY JOURNAL, *January* 29, 1916.

Comments on CAR OPERATION EFFICIENCY *by* F. E. WYNNE, *Engineer Railway Section, General Engineering Division, Westinghouse Electric & Manufacturing Company*

WESTINGHOUSE ELECTRIC & MANUFACTURING COMPANY
EAST PITTSBURGH, PA., *January* 11, 1916.

To the Editors:

A most interesting and valuable contribution to the literature on this subject is found in C. C. Chappelle's article in the issue of the ELECTRIC RAILWAY JOURNAL for January 15. From time to time numerous engineering papers and articles have been presented using speed-time curves for the purpose of illustrating the effects of changing operating conditions as well as for determining the correct equipment to apply. The manufacturers of railway equipments have for years endeavored to assist the operating departments of the electric railways in thoroughly understanding the fundamental principles governing efficient operation of cars. In spite of the progress due to these efforts, there is much yet to be desired. Mr. Chappelle's discussion of these principles brings out a point which is frequently overlooked in practical operation; namely, that under a given set of conditions, the power input to the car is determined by what he designates as "time-element factors." Therefore, his article should be of great assistance in securing full appreciation of the possibilities for economy which may result from a careful analysis of operating conditions.

He mentions the large investment in present equipment and the impracticability of obtaining the maximum economy which might be secured by scrapping it and installing new equipment designed to take advantage of all the recent developments in the construction of cars and electrical apparatus. In this connection it is well to note that probably on many roads the rolling stock is being operated at less than its maximum efficiency. In such cases there exists the opportunity for the application of the fundamental principles to decrease operating expenses and improve service without incurring the great expense accompanying a complete change of equipment. A study of the service conditions will bring to light incorrect operating features such as overloaded and underloaded equipments, wrong gear ratios, slow acceleration and braking rates, stops of unnecessary length, poor arrangements of schedule, headway and layover, etc. It will also furnish the data required for making a logical application of the fundamental principles to correct such defects as may be discovered. Consideration of these facts in conjunction with Mr. Chappelle's article makes it evident that every railway operator should be fully acquainted with all the details of his service conditions in order to get the most economical results from the equipment which is under his control.

In the matter of determining the most economical schedule, only the cost of energy and the platform expense have been considered. Apparently, the maintenance and fixed charges also should be taken into account. However, these are minor factors in comparison with the cost of energy and crew wages, so that the general conclusions will not be affected materially. Evidently the total maintenance and fixed charges per car-mile would be decreased, although the value per car annually would be greater. It is important to remember that the benefits to be derived from higher schedules are greater when the platform expense is high as compared with the cost of energy. It is also interesting to note from Fig. 15 that the average per cent coasting for the most economical results is greater for Case "A" than for Case "B." This illustrates the fact that the numerous variables encountered make the problem somewhat different for each railway.

If schedule speeds for different runs and at different times of day are once adjusted to be the most economical in each case, Fig. 15 indicates that approximately equal amounts of coasting should be secured with stops varying in frequency over the range ordinarily found in city service. This being the case, the coasting time alone will indicate directly the relative efficiencies of various motormen. However, it is not always possible to adjust schedules to the most economical value on account of the necessity for maintaining certain headway and meeting competition. For instance, one motorman in all-day service might be 100 per cent efficient when securing 40 per cent coasting. On the same line, the rush-hour service might be such that an extra motorman on a tripper would be 100 per cent efficient with only 20 per cent coasting. Hence it is necessary to have a record of the number of stops and the standing time as well as the coasting time in order to make fair comparisons. A knowledge of the frequency and duration of stops is also necessary in order to satisfactorily analyze a service and determine from the analysis what schedules are the most economical. Such analysis followed by adjusting schedules to the most economical value will be highly profitable to many railways. An instrument for measuring and recording running time, coasting time, standing time and number of stops would make such an analysis a comparatively simple problem and also insure proper operation of the equipments on the economical schedules as determined.

F. E. Wynne,
Engineer Railway Section, General Engineering Division.

Reprinted by permission from Electric Railway Journal, *January* 22, 1916.

Comments on CAR OPERATION EFFICIENCY *by* H. ST. CLAIR PUTNAM, *of L. B. Stillwell, Consulting Engineers, 100 Broadway, New York City*

L. B. STILLWELL, *Consulting Engineers*
NEW YORK, *March* 20, 1916.

To the Editors:

I have read with interest Mr. Chappelle's analysis of the "Fundamental Principles of Car Operation Efficiency," as based upon the coasting element in the speed-time curve, which was published in the issue of the ELECTRIC RAILWAY JOURNAL for January 15, 1916. The theory of the coasting element of the speed-time curve, as measured by the coasting clock, was discussed in a paper on "Power Economy in Electric Railway Operation—Coasting Tests on the Manhattan Railway, New York," presented by me before the American Institute of Electrical Engineers on June 28, 1910.

The analysis now made by Mr. Chappelle reaches the same conclusions as were then presented, excepting that Mr. Chappelle has extended his analysis to include a general solution of the problem, and includes also a study of the relation between platform expense and the most economical schedule speed for any given equipment and condition of operation. This is a very interesting addition to the subject and should be of value to operating companies.

The useful energy absorbed in moving a train or car from one point to another depends only upon the train resistance, which, of course, includes the resistance due to grades and curves. The wasted energy appears as rheostat losses in acceleration, motor losses and energy absorbed in braking. Where the equipment for a road is already installed the useful energy required for a run over a given portion of the road is practically constant. As has been frequently pointed out, any method of operation that results in the application of the brakes at a lower speed tends to produce a saving in the energy used. Any method of operation that increases the amount of coasting decreases the speed at which the brakes are applied and tends to reduce the amount of energy wasted in braking, and hence also tends to reduce the amount of energy required for the operation of the train. In railway equipments as usually installed the relationship seems to be that an increase of 1 per cent in the amount of coasting results in a saving of approximately 1 per cent in the amount of energy used.

It has been called to my attention that in my paper above mentioned the paragraph referring to a momentary pause on the series point during acceleration, and the effect of such a pause on the amount of energy used, shows a result inconsistent with the general principle as set forth above. The general principle, however, is controlling in this case also, the discrepancy being caused by factors resulting from the use of the starting resistance.

The pausing on series position of the controller for a few seconds should not be confused with such operation as occurs in short runs encountered in congested districts of a surface line route, or in approaching curves and switches where series operation only is a special and unavoidable condition, with an equipment selected for normal multiple operation in reference to the average conditions encountered in service.

The result of a pause on the series point in acceleration is a reduction in the average rate of acceleration, and this results in a decrease in the amount of coasting, an increase in the speed at which braking is begun, and therefore an increase in the energy wasted in braking. There would then be a corresponding increase in the energy actually used in the operation of the train, unless it is offset by the reduction in the energy absorbed in the rheostat, due to the elimination of a part of the rheostat losses in the multiple position. The energy absorbed in the rheostat is not actually used in the movement of the train, but is absorbed in the rheostat before it reaches the motors. If the reduced voltage on the motors could be obtained in some other way, the general principle would hold true in this case as in all others. In the case where rheostat control is used, however, a slight pause on the series position in acceleration results in cutting out a material portion of the rheostat losses in the multiple position, because of the increase that has occurred in the speed of the train. This reduction in rheostat losses tends to offset the additional energy required because of the lower average rate of acceleration. For a very short pause on series, in acceleration, amounting to from one to three or four seconds, depending on the maximum speed of the equipment used and the rate of initial acceleration, the reduction in the energy losses in the rheostat may equal or exceed the increase in the actual energy input to the motors caused by the resulting lower average rate of acceleration. Under such circumstances there will be but little or no increase in the total energy taken by the equipment, or it may even decrease.

As the rheostat is in circuit in the multiple position for from, say, four to fifteen* seconds only, depending upon the maximum speed of the equipment and the initial rate of acceleration used, the possible pause that can produce this effect must, of course, be of short dura-

---

*This long period is found in heavy electric traction.

tion. As the saving in energy, if any, resulting from this method of operation increases the wear on brake-shoes and wheels and endangers the maintenance of the schedule, motormen should be instructed against pausing on the series point during acceleration. The best all-round results are obtained by getting up to speed as rapidly as practicable.

The disadvantages of rheostatic control have been long recognized, but the rheostat is the most practical device available for d.c. motor control. Where it is possible to obtain voltage control directly, as in alternating-current operation or by field regulation in direct-current operation, then the general principle is of universal application. It can be stated generally, therefore, that any method of operation that increases the amount of coasting decreases the amount of energy required for the operation of the train.

H. S. PUTNAM.
Consulting Engineer.

Reprinted by permission from ELECTRIC RAILWAY JOURNAL, *April* 1, 1916

Chapter Three

Relation Between Car Operation and Power Consumption

Chapter Three

Relation Between Car Operation and Power Consumption*

By J. F. LAYNG

Railway and Traction Engineering Department,
General Electric Company

SINCE the early days of electric railroading it has been known that in test runs there are great differences between power used, even when the conditions of service are the same. With the same car over the same route, with the same number and length of stops, the power consumption will vary more than 30 per cent when operated by different motormen. This is a case where the difference between individuals is strongly emphasized.

It is also recognized that with the same motorman on different days the power used will vary greatly. If he feels strong and in a good humor the motorman accelerates fast and saves power, but if he feels otherwise he will accelerate slowly and consequently waste power in starting resistors. Weather conditions, of course, will cause variation in the amount of power used, but with reference to the remarks just made, it is assumed that weather conditions are normal.

The difference in power consumption in the different runs is caused by the relative amount of coasting and rate of braking by the different men.

The maximum amount of coasting is obtained when a car is accelerated at a maximum rate and decelerated at a maximum rate. When a car is accelerated rapidly instead of slowly, the starting resistor is in use for a proportionately shorter length of time and consequently the difference in the energy consumption is transferred from rheostatic losses to useful work.

A few years ago there were a number of investigations made to determine some systematic method of securing the maximum coasting at all times, and as a result the coasting clock was designed and is now very extensively used throughout the country.

Two other methods that have been used in a number of instances to obtain the maximum coasting consist in employing wattmeters and ampere-hour meters. With these two instruments it is of course necessary to make proper allowance for the difference in the weight of cars when making an analysis. Recently there has been considerable data published regarding the methods of obtaining the maximum amount of coasting, and it would therefore seem advisable to make an analysis of the fundamentals which will illustrate in curve form just what can be expected in energy savings by accelerating and decelerating as rapidly as possible.

To illustrate these points, calculations and curves have been made on cars weighing 18 tons complete with load, and equipped with two motors. It is assumed that the car is geared to have a free running speed of 22 miles per hour, a 1000 ft. run, a schedule speed of 10.65 miles per hour, 7-second stops, and 20 lb. per ton friction. As has been previously stated, with maximum rates of acceleration and deceleration the maximum amount of coasting is obtained.

The curves shown in Fig. 1 illustrate the amount of power which will be required per ton mile when accelerating at different rates, that is, ¾, 1 ,1¼, 1½ and 2 miles per hour per second. The amounts of current are also plotted on these curves.

A study of the amounts of energy required for the different rates of acceleration is very interesting. When accelerating at ¾ miles per hour per second, it is found that the power con-

---

*Reprinted by permission from October 1915 issue General Electric Review.

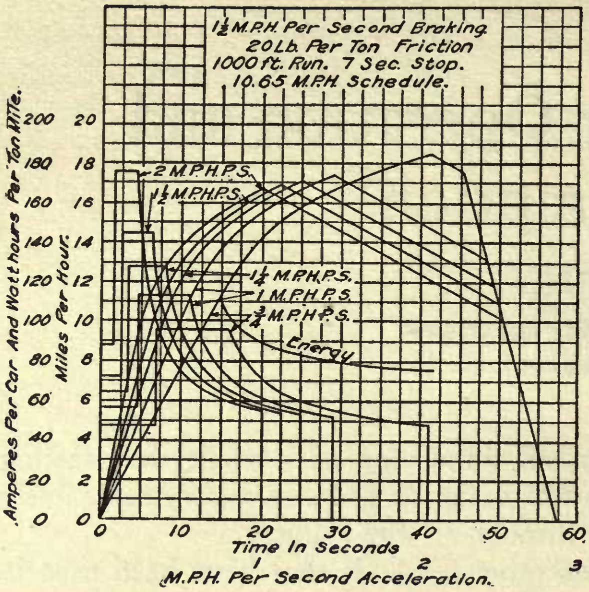


Figure 1

Decrease in Energy as Rate of Acceleration is Increased

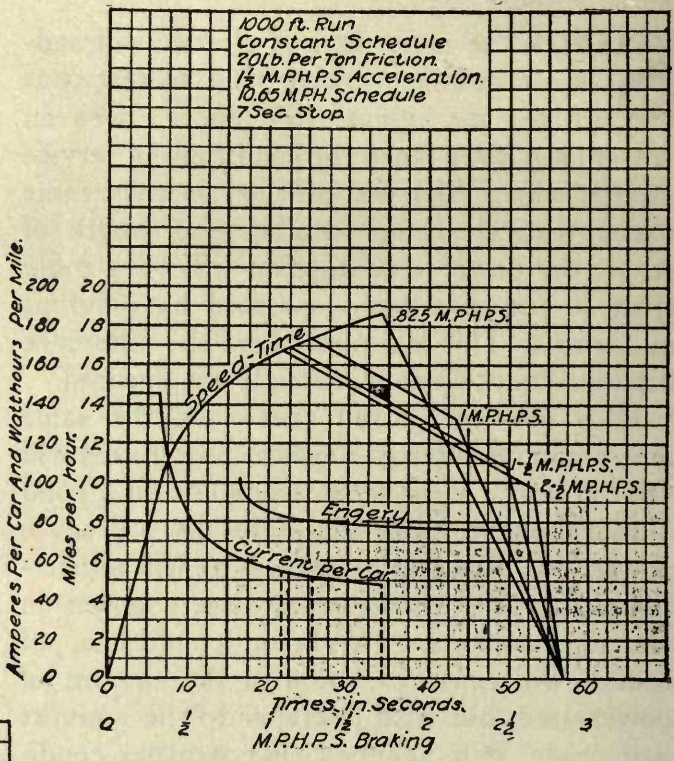


Figure 2

Decrease in Energy Consumption as Rate of Braking is Increased

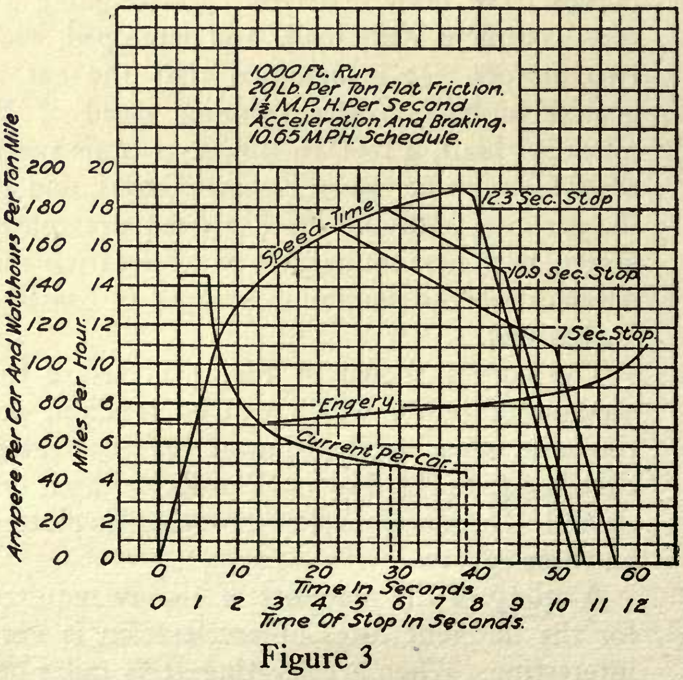


Figure 3

Increase of Energy Consumption for a given Run and Schedule as the Time of Stop is Increased sumption is 110 watthours per ton mile. When accelerating at 1 mile per hour per second this is reduced to 80 watt-hours per ton mile, and when accelerating at 1¼, 1½ and 2 miles per hour per second the energy required will be 83, 79, and 76 watthours per ton mile respectively.

The difference in energy saving is considerably less between the higher rates of acceleration than between the extremely low rates; it will be noticed that the difference between the 110 watthours and 90 watthours is 19 per cent, while the difference between 90, 83, 79 and 76 will be 7, 5, and 3.8 per cent, respectively. Therefore it will be appreciated that while there is some considerable saving between accelerating at 1½ miles per hour per second and 2 miles per hour per second still at the same time the saving is considerably less than in rates of acceleration lower than this value.

Fig. 2 has been made to illustrate the value of braking or decelerating at different rates, and is based on the same data as given in Fig. 1. This curve is made up on the basis of accelerating at 1½ miles per hour per second. The rates of deceleration chosen are 0.825, 1, 1½ and 2 miles per hour per second. The additional amount of coasting which is obtained will enable current to be cut off from the motors sooner than when braking at some relatively lower rate, and a greater amount of coasting will be obtained. The energy required for the different rates of deceleration are respectively, 100, 85, 79 and 76 watt-hours per ton mile.

The difference between 100 watthours per ton mile and 85 watthours per ton mile is 15 per cent, and the difference between the other values are 7.5 per cent and 4 per cent respectively. It will therefore be seen that the difference between decelerating at the most rapid rate on the curve and the lower rate on the curve gives a saving of 24 per cent in energy.

The difference in accelerating from the lower to the higher rate, as shown in Fig. 1, gives a saving of 31 per cent. These values when considered separately can actually be obtained, but there are points between the lowest rate of acceleration and the lowest rate of braking where the lines cross.

It is generally accepted that the proper rate of acceleration and braking is in the neighborhood of 1½ miles per hour per second. However, there are some cities in the United States where, due to exceptional conditions, it is deemed advisable to accelerate and decelerate at 2 miles per hour per second. This of course gives the highest possible schedule speeds, which of necessity gives the largest number of car miles per hour which can be obtained, and in this manner the greatest use of a car is obtainable.

It has also long been recognized that by carefully following up the motorman's instruction with the assistance of coasting clocks, ampere-hour meters or wattmeters, the motorman will realize the advantages which will accrue from coasting, and in this way great savings will be made in power, brake shoes, and wheels. Coasting records also show whether it is possible to decrease the number of cars on a given line, and give a direct indication of how much leeway there is in schedules. There are other ways in which power can be saved, that is, by decreasing the length of stop and also slightly extending the schedule speeds. Analysis of many conditions will show that in some cases by very slightly extending the running time considerable power can be saved.

Fig. 3 illustrates the amount of power which can be saved when making the same schedule as has been previously outlined in Figs. 1 and 2. With 4, 8 and 12-second stops the energy required to propel the car will be 74, 80, and 105 watthours per ton mile respectively, which shows a saving in energy of 22.8 per cent between the 8-second and 12-second stop. To maintain the same schedule with a 12.3-second stop will require 41.8 per cent additional energy when compared with a 4-second stop.

Fig. 4 illustrates what can be done by extending the schedule speeds. With an actual running time of 52 seconds, 115 watthours per ton mile are required. By extending the actual running time of this run to 53 seconds, there is a power saving of 22½ per cent.

Of course, it is not practicable to operate a schedule with absolutely no coasting, such as the 52-second run, but these figures illustrate the value of a small working leeway in running time.

It will be noted that the actual running time, not including stop, is extended to 80 seconds, and that the energy is reduced to 54 watthours per ton mile, but the schedule has been reduced from 11.7 miles per hour to 7.8 miles per hour when considering the entire range which is covered by the curve.

The last two sets of curves which have just been discussed are entirely separate from the first two curves. The first curves illustrate certain fixed conditions with reference to schedule speed, length of run and length of stop, while the last two curves assume the operating conditions to be changed, that is, by changing the length of stop or extending the schedule speed.

After reviewing the four series of curves given, there can be but two conclusions, viz.: the effort to keep track of power consumption and to instruct the motorman is a very profitable undertaking, and that there is as much reason for following up and keeping tab of the energy used by individual motormen as there is for keeping record of any other expenditures on the property.

By keeping these records and following them up properly, savings in power of 20 to 25 per cent can reasonably be expected. In many cases a study of the local conditions will show how schedules can be slightly rearranged and either less cars used for a given service, or the running time can be very slightly extended and the power savings made which are illustrated in the curves of Fig. 4.

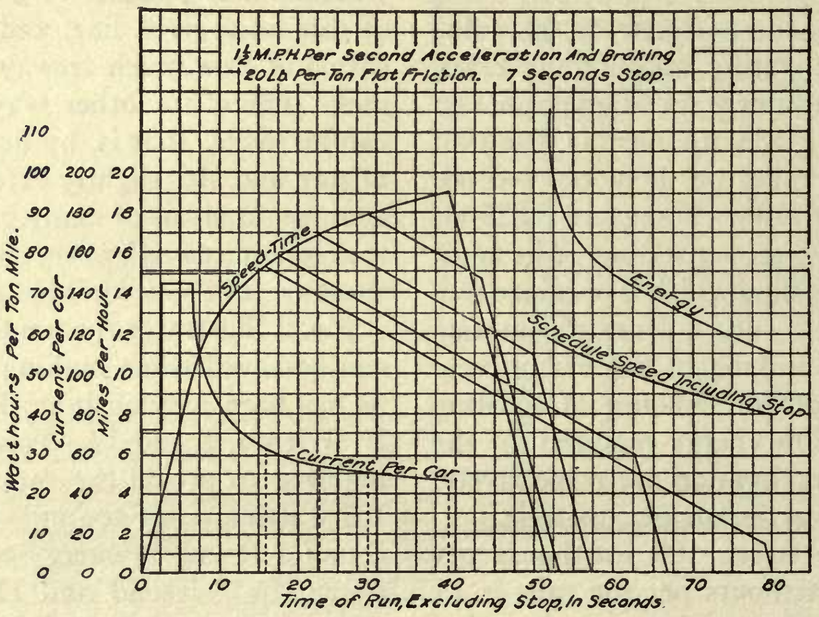


Figure 4

Decrease in Energy Consumption, Current Input, and Schedule Speed by Increasing the Coasting in a 1000-ft. Run

Chapter Four

Economies in Railway Operation

Chapter Four

Innovations in Railway Operation

Chapter Four

Economies in Railway Operation

By F. E. WYNNE

Engineer Railway Section, General Engineering Division
Westinghouse Electric & Manufacturing Company

NOTE: Through the courtesy of Mr. F. E. Wynne we have reprinted in this Chapter IV, portions of his paper read in 1912 before the Baltimore Section of the American Institute of Electrical Engineers. Mr. Wynne discusses several elements and factors that can effect economy of operation. Some of these can be correctly determined as to their adaptability in the selection of equipment, while others are controlled more or less entirely by the operations of the motorman or the motorman and conductor. To apply most effectively the principles discussed by Mr. Wynne in reference to gear ratio, type of control, etc., it is necessary to have an accurate record of the traffic conditions and requirements, while the economies he shows as obtainable in the correct operation of cars in service can only be attained by means of an effective and constant checking of the actual operations of every car. It will be apparent that the foregoing necessary requirements are effectively accomplished only by means of the Rico Coasting Recorder or the Rico C & S Recorder. [C. C. Chappelle.]

NEVER before in the history of modern industrialism has there been such a stupendous effort made by everyone for high efficiency as at the present time. It is the keynote of every convention; the proceedings of the Institute and other engineering societies are full of it; magazines and daily papers are devoting a great deal of space to the subject.

Under such conditions it is natural that the pendulum in railway operation, which has until recently been swinging far upon the side of safety and reliability at any cost, started to swing toward the side of reduction in cost at the price, as some engineers think, of both safety and reliability. When this happens, an extreme is likely to be reached that may show a reduction in cost of some items that have been in the limelight, but will show an increase in other items affected thereby that will far outweigh the reduction.

The way to avoid such an undesirable condition of affairs is to analyze carefully every point and study it from all sides before making a change from practice that is giving good results. In other words, the old maxim, "be sure you are right, then go ahead," applies here with special force.

Probably nowhere has this search for efficiency been more active than in the electric railway field. In the first place every part of the equipment has been studied with the greatest care to increase its life and reliability and decrease the cost of maintenance. This has resulted in the present magnificent equipments that are found on all up-to-date roads. Car bodies, trucks, wheels, control and motors have all improved to an extent undreamed of a few years ago. Not only has there been a great increase in reliability—which is always one of the greatest assets a road can have—but the cost of inspection and maintenance has been reduced to a degree that makes it cheaper to scrap old equipments than to operate them.

Since the life of wearing parts has been increased to an extent that but little return may be expected from further endeavors along that line, the busy minds of engineers all over the country have been turned toward other means of reducing cost of operation and have naturally rested on the cost of power. This is usually one of the larger items in the cost of operation and offers a fruitful field for investigation.

A great many engineers have figured out the amount it costs to carry around the dead weight of a car and have given figures varying from 3 cents to 10 cents per pound per year. These figures must, of course, depend on the mileage, the cost of power per kilowatt-hour at the car, and the kind of service. For instance, the mileage of cars may vary from 15,000 to 90,000 miles per annum. Power may cost in one place .4 cent per kilowatt-hour at the switchboard, and in another may run twice that amount. Then the cost of getting a kilowatt-hour from the power house to the car varies widely. Finally, the conditions of service may vary so much as to take anywhere from 40 to 150 watthours per ton-mile at the car

A road which averages 50,000 miles per car per annum, consuming 100 watthours per ton-mile at the car, and whose power costs 1.5 cents per kilowatt-hour at the car, will pay 3¾ cents per pound per annum for power.

$$\frac{50{,}000 \times .100 \times 1.5}{2000} = 3\tfrac{3}{4}$$

But whatever the actual cost may be, it has put the matter before the operating people in such an attractive way that many of them have been bending every energy to reducing weight, thinking that every pound reduced, no matter how reduced, will result in an immediate saving of 5 cents per pound per annum. Some even go so far as to say that every pound removed from the dead weight of a car is worth 75 cents to them—off the car.

This is the kind of talk that must be accepted with a good deal of salt. It is, no doubt, true that if the cost of operation per ton-mile remains the same with the lighter weight cars and equipments, the saving will be made. The danger is that in reducing the weight, conditions may be altered so much as to make the cost of operation more than before. The cost of inspection and maintenance may be increased on account of the necessity for more frequent renewals of wearing parts.

It is intended to discuss in this paper some of the proposed means for saving power on electric railroads and to clear up, if possible, some of the misunderstandings that exist at the present time.

[I]

Reduction of Weight

In the development of the electric railways, the evolution of cars and equipments from the old horse cars to the modern double-truck city cars and the high-speed interurban cars, has been attended by much grief and loss. The development was so rapid that the only method possible to pursue was to build the car and equip it, using the best judgment obtainable in proportioning the parts.

Where parts broke in service, they were usually strengthened by increasing weight and section, regardless of the actual cause of the break, which might have been in something entirely different. This, of course, resulted in designs which were unnecessarily heavy. It is the part of good designers and conservative engineers to redesign them, distributing material where necessary for strength and cutting out as much unnecessary material as possible.

It is astonishing what results have already been obtained in this line, and the end is not yet. The use of high-grade materials and pressed-steel shapes with new types especially fitted for them will still further reduce weights of car bodies and trucks, and now the question has been put squarely up to the electrical manufacturers to reduce the weight of the motors and control apparatus.

[II]

Proper Gearing and Armature Speed

*"The selection of improper gear ratios for railway-motor equipments has alone caused a loss of hundreds of thousands of dollars to the operating and manufacturing companies in this country. Motors have been overloaded and burned out by the thousands. Fifty horsepower motors have been used where 40 horsepower motors would have done equally well if properly geared. Power houses and substations have been overloaded, have had their load factor greatly decreased and the line loss has been greatly increased, simply because the motors on the cars have been geared for too high speeds. Few people who have not made a special study of the subject realize its importance, and at the present time, in spite of the campaign which has been waged against it by the manufacturing companies and a few enlightened engineers, there are still a good many motors in service which are so geared as to result in a continual loss to the operating company. The large companies have been realizing more and more in recent years the disadvantages of high-speed gearing and some of them are now making wholesale changes in their gearing, reducing the maximum speeds and making savings of 5 to 12 per cent in power

---

*N. W. Storer in ELECTRIC JOURNAL, volume 5, page 510.

consumption, besides greatly reducing the temperature of the motors."

Probably 5 to 10 per cent of all the power used for propelling electric cars and trains could be saved by correct gearing.

The maximum gear reduction varies from 3.5:1 to 5:1, depending upon the power of the motor. The armature speed at the 500-volt rating of the motor varies from about 500 to 650 revolutions per minute. Therefore, with maximum reduction and minimum wheel diameter, the car speed at full load of the motors varies between about 10 and 18 miles per hour. Even motors of the same power are built for such speeds that with the same gearing, the car speeds differ by as much as 25 per cent. The opportunity for incorrect motor application, particularly where stops are frequent, is therefore apparent.

[A] CITY SERVICE

By city service we mean the service in the larger cities where stops average seven (7) or more per mile and are fairly evenly distributed. In such service there is very little or no running at full speed. The essentials for maintaining the schedule are rapid acceleration and braking. In most cases there is no difficulty in keeping cars on time with the motors geared with the maximum reduction. Under such conditions a motor of low revolutions per minute with the same gear reduction will do either one or two things: it will give the same rate of acceleration with less current or with the same current it will give a higher rate of acceleration than the motor of higher revolutions per minute. Both of these features tend to reduce the power consumed.

As an illustration compare the shorter runs in Figs. 1 and 2. In each case train, grade and curve resistance has been taken at 22 pounds per ton. The slow-speed motor of Fig. 2 takes the same accelerating current as the high-speed motor of Fig. 1. Because of the quicker start with the slow-speed motor, the heavy current does not last so long, the same amount of coasting is obtained, and the brakes are applied at a lower speed. The gain in power consumption in favor of the slow-speed motor is 10.9 per cent. Part of this saving is the result of lower rheostatic losses and the balance is due to the smaller amount of stored energy wasted in the braking process.

It should be noted that the gain of 10.9 per cent is in total power consumed and is in spite of the extra weight of car with the slow-speed motor. It is further worthy of note that the heating of the high-speed motor is the greater.

These curves will also serve to illustrate the effect of gear ratio. The high-speed motor corresponds to the slow-speed motor with a 4.43:1 gear reduction. However, in this instance, the car weights should be the same so that the difference in favor of the slow-speed gearing is even a little greater than the 13.8 per cent saving indicated by the watthour per ton-mile values of the figures.

The motor speeds used are within the limits of commercial apparatus and the gearing is within the limits found on the same motors

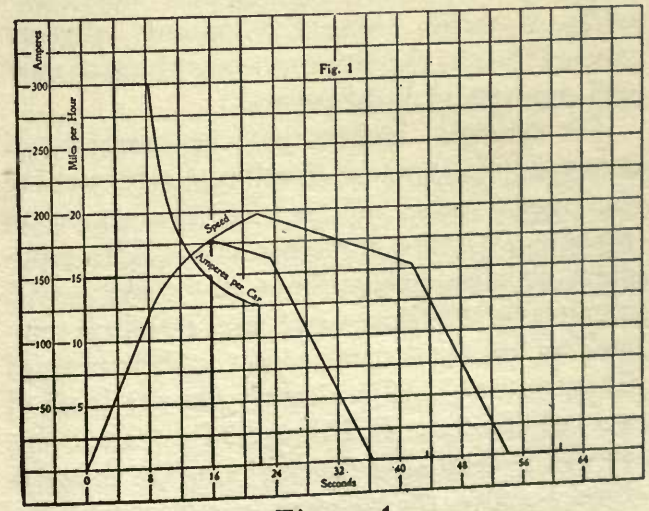


Figure 1

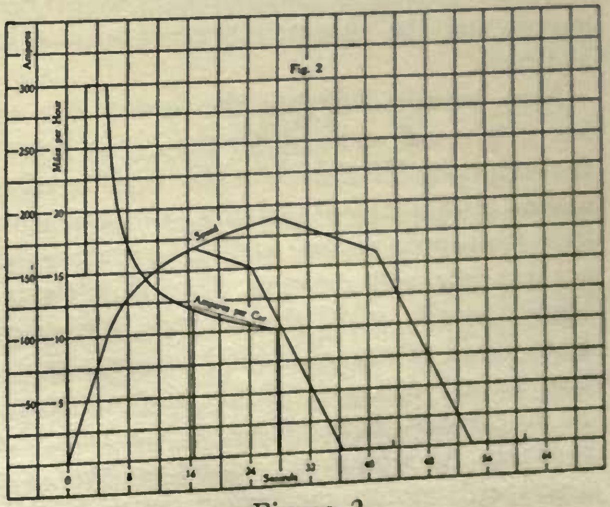


Figure 2

in the same service, so that actual service conditions are represented.

The argument most frequently heard against the adoption of slow armature speed and high-gear ratios for city service is that the car speed will be so slow that the running time will be greater.

Let us examine this contention and see of how much value it really is. Figs. 1 and 2 show that the two motors made the schedule equally well. The higher acceleration is obtained with the slow-speed motor without subjecting the equipment to any heavier current. The amount of coasting is practically the same, so that if the runs were made without any coast, the times would be the same. The high-speed motor is already slightly overworked, so there is no hope of making a faster schedule by forcing its rate of acceleration up to the value which is safe with the slow-speed motor. Neither can the high-speed motor take advantage of more rapid braking to increase the schedule speed. However, since the slow-speed motor is not yet worked up to its full capacity, it can use faster braking to a certain extent without being overloaded.

The figures given above show the saving in power at the car. This is further augmented by the accompanying reduction in losses throughout the system from the cars to the coal pile on account of the reduction in the duration of peaks and the improved load factor with slow-speed motors. Therefore, the figures given are conservative. The assumption of equal gear reduction is fair because the maximum gearing is fixed by the power of the motors and the clearance between gear case and track.

Now consider whether the saving due to less weight will make up for the loss in power consumption. If the car under consideration makes 30,000 miles annually, the car with light high-speed motors at 4.21 kilowatt-hours per car-mile will consume 126,300 kilowatt-hours annually, while the car with slow-speed motors will consume 112,500 kilowatt-hours. The annual saving is 13,800 kilowatt-hours. At 1 cent per kilowatt-hour, this amounts to $138.00. At 5 cents per pound per year, the high-speed motor car would save $100.00 annually. The net saving is $38.00 annually in favor of the slow-speed motor. The actual difference is more than this because part of the saving of 5 cents per pound annually is based on reduced power consumption with the high-speed motor. We have shown that this basis is incorrect.

If the heavier car consumed the same energy per ton-mile (145 watt-hours) as the lighter car, the latter would save in energy 4350 kilowatt-hours annually. Hence, $43.50 of the $100.00 annual saving credited to the light motor above is not really obtained and the actual net saving for the slow-speed motor is $81.50 per year.

Many railway systems are facing the problem of operating more cars, while their generating and distributing systems are already loaded to their full capacity. The reduction in power consumption with slow-speed motors would mean that more cars could be operated without increasing the generating and distributing capacity. So the questions of motor speed and gearing are exceedingly important when considering the installation of a new system or a new line. It is unfortunate that this has not been better appreciated in the past.

[B] COMBINED CITY AND SUBURBAN SERVICE

Here are considered those lines giving a mixed service consisting in part of city service as defined above and in part of a service averaging four or five stops per mile, with more or less well-defined limits.

In this class of service the same general principles hold as for city service. The possibility of using high-speed is only slightly greater than in the city service as the stops are still comparatively frequent.

For example, assume that the operation of a certain line comprises 6 miles of city running with nine stops per mile and 6 miles of suburban running with five stops per mile. The minimum running time without any coast is 68.8 minutes for the slow-speed motor and 68 minutes for the high speed motor, a difference of 0.8 minute or 1.16 per cent. On the basis of a scheduled time of 81 minutes for the run one way and operation of the two motors as shown in Figs. 1 and 2, the power consumption with the high-speed motor is 42.54 kilowatt-hours per trip and with the slow-speed motor is 39.9 kilowatt-hours per trip, the latter saving 6.2 per cent of the energy required by the former.

In this class of service the annual car-mileage is generally higher than in city service only, on account of the longer trips, somewhat higher average speeds, and smaller difference between the average and maximum number of cars required at different times of the day and year. Assuming 40,000 miles per car yearly and power at 1 cent per kilowatt-hour, the saving by using the slow-speed motor instead of the high-speed motor amounts to $46.00 annually.

[C] INTERURBAN SERVICE

Practically all interurban railways enter one or more large towns or cities over tracks laid in the streets for several miles. This condition generally requires slow-speed running whether the stops are few or frequent and, therefore, this part of the service is most economically maintained by the slowest-speed gearing suitable for the other service. Many of these railways give both local and limited service. It is of course desirable to use the same motor and same gear ratio for both classes of service. With the same gearing, the local service, because of the more frequent stops, will work the motors more nearly up to their full capacity than will the limited service. The limited service is most often considerably less than half of the total.

In order to minimize the size of equipment and get the maximum economy of power, the gear ratio should be selected on the basis of the local service, and the limited schedule adjusted to suit the equipment and gearing best adapted to the local service.

If a high-speed limited schedule is taken as the basis of choosing the gear ratio, one of two evils frequently results: (1) a small equipment geared for abnormally high speed and just able to maintain the limited schedule nicely is selected with the inevitable result of overheating the motors in local service, roasting out the windings, loosening connections and consuming an unwarranted amount of power; or (2) a large equipment geared to maintain the limited schedule and yet of sufficient capacity to perform the local service without overheating is chosen, with the result that the power consumed in local service is excessive and equipments are heavier than need be for the major portion of the service.

With the large motor geared for a high-limited schedule, the heating in local service is as great as with the smaller motor properly geared for the local service.

Large high-speed equipments collect their toll all along the line through extra weight, first cost, cost of maintenance, cost of power, greater feeder capacity, larger substations and larger power houses. Is it worth the price? We believe it is not. In certain cases of keen competition it may rise to the dignity of a *necessary* evil, but too often high speed is assumed as the essential element in building and maintaining traffic, when in reality the frequent service and ability to receive and deliver passengers at several central points in the terminals and towns served assures all the profitable traffic.

In the last analysis we believe that the extra cost of excessively high-speed limited service is rarely equalled by the additional revenue obtained on account of the excess in speed over what could be secured with equipments geared for moderate speed.

Table II shows that the energy *power* consumption per car-mile for local service is 2.4 kilowatt-hours with 75-horsepower motors and 2.7 kilowatt-hours with 90-horsepower motors, and for limited service is 2.03 kilowatt-hours and 2.39 kilowatt-hours with the 75-horsepower and 90-horsepower motors, respectively.

[III]

Correct Operation

We have shown that very great economies may be obtained by selecting motors of the proper armature speed and correct gearing. In addition to these, a great saving in power consumption may be secured by correct operation of the cars in service. By correct operation is meant the use of proper accelerating and braking rates so as to obtain the greatest amount of coasting consistent with the particular equipment used in any given service.

[A] ACCELERATION

It is frequently found that where a road is operating under a fairly easy schedule, the motormen will accelerate rather slowly and perhaps operate with the motors connected in series for a considerable part of the time. The limits to the rate of acceleration are the strains on the car and equipment and the comfort of the passengers, so that all of these features should be considered in determining the maximum rate of acceleration which is permissible in any given case. So far as comfort is concerned, rates of acceleration up to 2 miles per hour per second are in use without objection on the part of the passengers.

Fig. 4 shows a run of one mile at a schedule speed of 24 miles per hour with various rates of acceleration. The car weight is 38 tons and the equipment comprises four motors each rating 75-horsepower at 500 volts. The braking rate is constant at 1.25 miles per hour per second. A consideration of this figure shows that by varying the acceleration from 0.75 miles per hour per second to 1.5 miles per hour per second, the power consumption may be reduced 29.6 per cent. It should be noted in this connection, however, that the maximum current requirements vary from 370 amperes per car with the lowest rate of acceleration to 570 amperes per car with the highest rate of acceleration. Hence, substation and line capacity must be considered in many instances.

[B] COASTING

The amount of coasting obtained is a fairly good measure of the difference in power consumption for a given run made under different conditions; because, when the amount of coasting is great, it usually means that the acceleration is rapid and that the braking rate is also high. The actual economy obtained by increasing the amount of coasting in any given service is not effected during the coasting period itself, but is the result of (1) more rapid acceleration with power taken from the line a decreased proportion of the time and (2) of a higher braking rate with decreased waste of energy in heating the brake shoes and wheels.

[C] BRAKING

Other things remaining the same, an increase in the braking rate produces a decrease in power consumption because the brakes will be applied at a lower speed and consequently there will be less of the stored energy of the car consumed during the braking period. This saving is indicated directly by the decreased time during which it is required to supply power to the car in order to maintain a given schedule.

Fig. 5 shows the same run as in Fig. 4 except that a constant accelerating rate is maintained and the braking rate is varied.

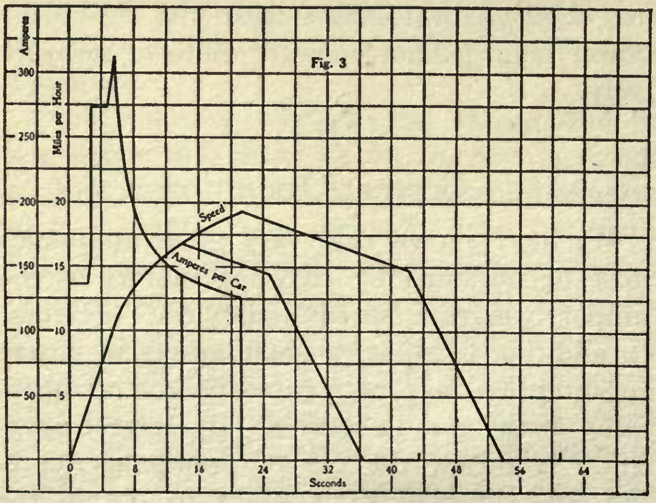
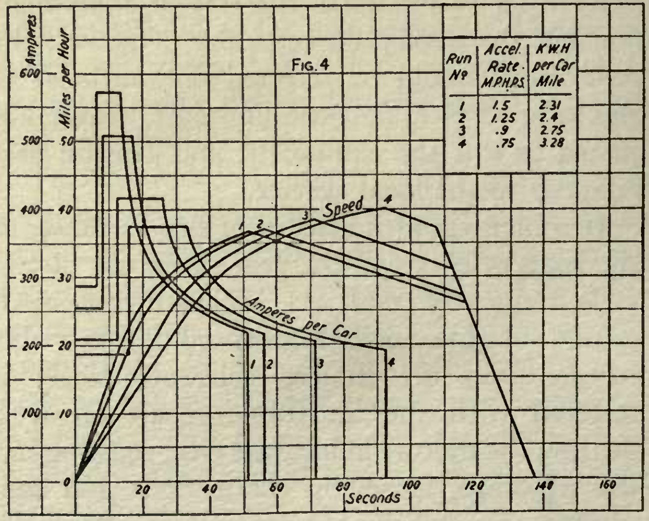


Figure 3



Run Nº	Accel. Rate. M.P.H.P.S.	K.W.H per Car Mile
1	1.5	2.31
2	1.25	2.4
3	.9	2.75
4	.75	3.28

Figure 4

By varying the braking rate from 0.8 miles per hour per second to 2.0 miles per hour per second, the power consumption is reduced 23.1 per cent.

Fig. 9 is a general curve showing the rheostatic losses in an equipment plotted against the speed at which the rheostats are all cut out of circuit; the stored energy in a car at any speed; and the power input to the car in bringing it from rest up to any given speed. The energy to propel a car is utilized in heating the electrical equipment, overcoming rheostatic losses in starting, in heating brake shoes and wheels and in overcoming the friction and windage due to operating the car in service. The latter item is the useful work and is practically constant for a given service irrespective of the method of operation.

By using a motor so designed and geared that the rheostats will all be cut out of circuit at a low speed, the rheostatic losses will be below those obtained when the rheostats are cut out of circuit at a higher speed. With a given equipment, increasing the rate of acceleration produces this result. Higher rates of acceleration permit the car to coast to a lower speed before the brakes are applied and therefore less energy is wasted in heating the brake shoes and wheels. High rates of braking accomplish the same result.

The curve on Fig. 9 marked "Rheostatic Losses" shows what may be accomplished by cutting out the rheostats more quickly. The curve marked "Stored Energy No Rotational" gives a measure of the amount of energy wasted in braking from any given speed and shows what may be accomplished by applying the brakes at a lower car speed. This curve is used in preference to the one including the energy of rotation in armatures, gears, wheels and axles since this rotational energy will be about balanced by the train resistance while braking. The curves for field control will be considered later.

[IV]

Field Control

The control of the speed of railway motors by changing the effective turns on the field is as old as railway motors. Practically all of the early double reduction motors were controlled in that way. Some few single reduction motors were also controlled in that way and the old "loop" system was quite familiar 15 years ago. It was a failure at that time chiefly because of difficulties with commutation due to poor motor design. Its advantages have remained fresh in the minds of some engineers, however, and when the locomotives for the New York, New Haven & Hartford Railway were designed in 1905, they were arranged for

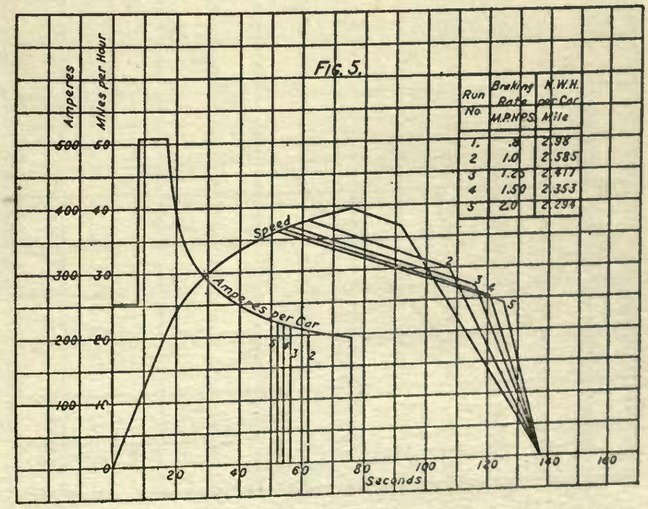


Figure 5

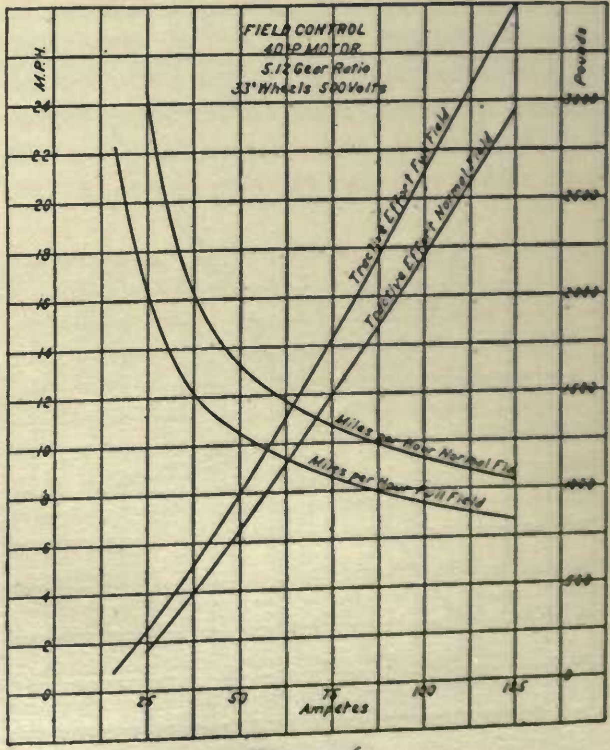


Figure 6

speed control on direct current by shunting the field. Forty-one locomotives have been in operation with this system of control on this road for the last five years and it has proven entirely satisfactory.

When the giant Pennsylvania locomotives were designed, the requirements for large tractive effort in starting and high maximum speed were so severe that it was necessary to use field control of the motors. The application was slightly different from that of the New Haven locomotives, however; instead of shunting the field, half of it is cut out on the final notches in series and parallel. This is to avoid having a non-inductive shunt around the field which with a solid frame machine might be productive of flashing. This is the scheme which has since been tried with great success on motors for city and interurban cars.

The question that naturally arises is, what are the advantages of this system? The answer is brief, to save power. How is this accomplished? On the same general principle which saves power by the use of slow-speed motors and high gear ratios; namely, more efficient acceleration.

In Fig. 9, the rheostatic losses with field control are less than for the same speed with ordinary control because field control is used in series in place of the last resistance step.

Fig. 6 shows the speed and tractive effort curves of a 40-horsepower field control motor with maximum gear ratio and 33-inch wheels.

Fig. 7 shows the characteristics of the corresponding slow-speed motor without field control, and Fig. 8, the corresponding light-weight motor.

From these curves it is seen that the speed of the field control motor on normal field is about the same as that of the slow-speed motor without field control, while the speed of the field control motor on full field is very low. The full field is used in accelerating and therefore the rheostatic losses are greatly reduced. The normal speed is used for running and enables the car to attain the same speeds as with the non-field control motor, so that the braking losses are not increased.

The following example will serve to show the saving which may be obtained by field control. Suppose that the tractive effort per motor required to give the necessary acceleration is 1575 pounds. With a non-field control motor this takes 75 amperes and with a field

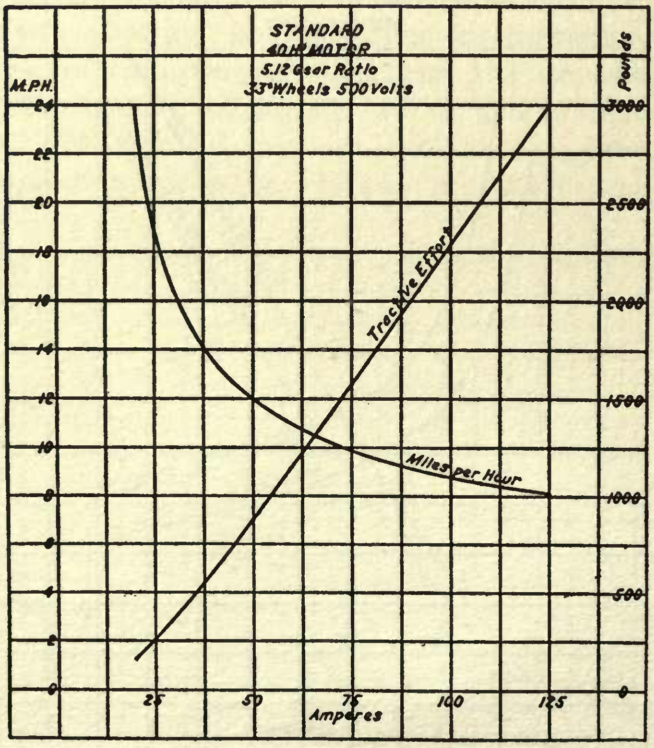


Figure 7

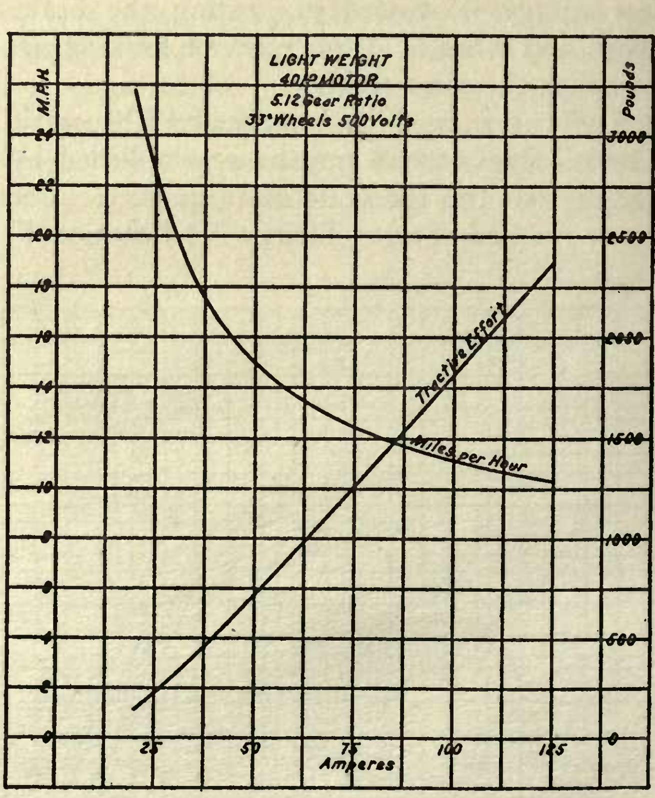


Figure 8

control motor only 68.5 amperes. The rheostatic losses are all cut out at 8.9 miles per hour with field control motor, but are not cut out until a speed of 9.9 miles per hour is reached with the non-field control motor. Reference to the general curve Fig. 9 will show that the corresponding rheostatic losses are 1.07 watt-hours per ton with the field control motor and 1.62 watt-hours per ton with the non-field control motor. In other words, the field control motor saves 0.55 watt-hours per ton every time the car starts. If the car weighs 30 tons and makes 9 stops and starts per mile, the saving is 0.149 kilowatt-hour per car-mile.

Fig. 3 shows the same run as in Figs. 1 and 2 made with the same acceleration as used for the slow-speed motor in Fig. 2.

Table 1 gives the results from Figs. 1, 2 and 3. The power consumed is 3.39 kilowatt-hour per car-mile, or 9.6 per cent less than with the slow-speed motor of Fig. 2 and 19.5 per cent less than with the high-speed motor of Fig. 1. In this case, the use of a slow-speed motor instead of a high-speed motor reduces power consumption 10.9 per cent while the use of field control makes a further reduction of 9.6 per cent and the combination of slow-speed motor and field control produces a saving of 19.5 per cent.

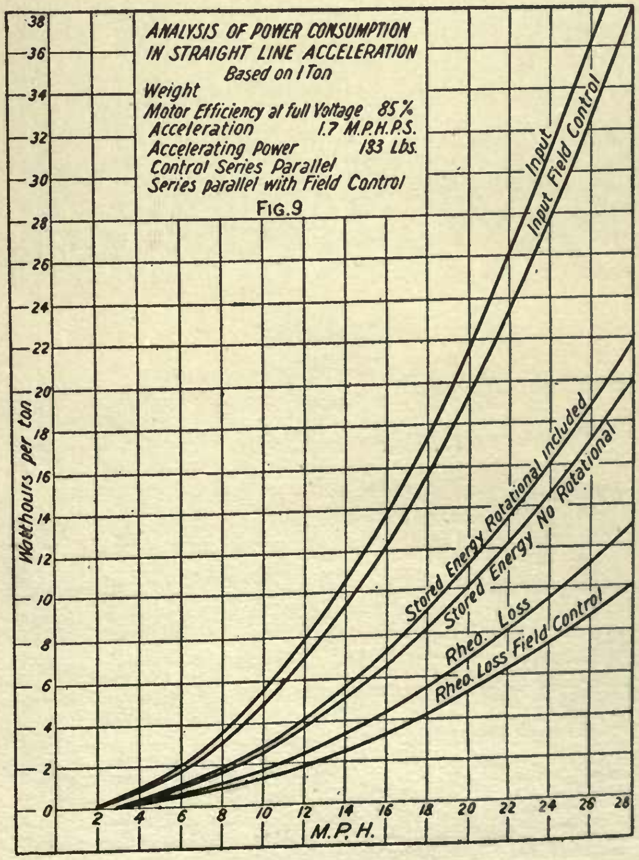


Figure 9

For a combined city and suburban service similar results are obtained. The application of field control to the example of this class previously considered under Section II, shows that the field control motor will make the trip with 35.76 kilowatt-hour and therefore will save 10.4 per cent of the power used by the slow-speed motor and 15.9 per cent of that required by the high-speed motor.

For interurban service, field control produces more economical running over the slow-speed city sections, permits the use of a gear ratio which is economical for local service and with the same gearing gives a higher limited speed than could be obtained with the same size non-field control motor geared for the local schedule. This tends not only toward economy in local service, but also toward reducing the motor capacity required for the operation of frequent-stop local service and high-speed limited service with the same gear ratio.

A 75-horsepower field control motor geared for the local service, as heretofore described, and operating as shown in Fig. 10, will maintain a limited schedule speed of 38.4 miles per hour, which is the same as that possible with the next size larger non-field control motor. At the same time the reduction in power consumption is 15.9 per cent for local service and 11.7 per cent for limited service. The power con-

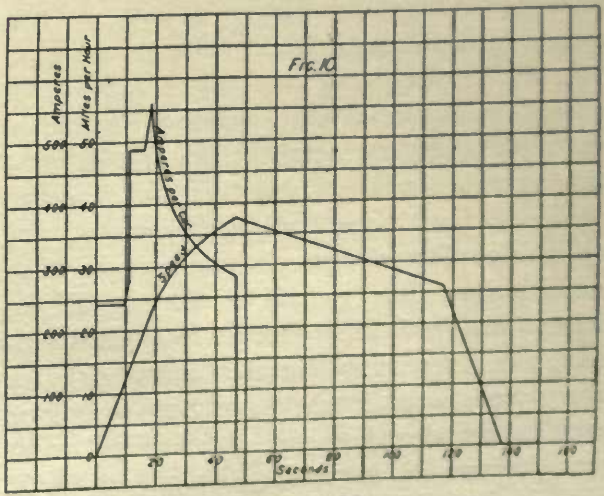


Figure 10

sumption in limited service is somewhat more than with the ordinary 75-horsepower motor on account of the faster schedule speed maintained with the field control motor. The comparative results are shown in Table II.

[V]

Results of Tests

Within the last few years a number of tests have been made on cars operating in regular service, the results of which show that our contentions in respect to proper gearing and armature speed, correct operation and field control are correct in practice as well as in theory.

Table IV shows the results of tests made in December, 1910, under the direction of the writer, on the Frankstown Avenue line of the Pittsburgh Railways Company. The cars and equipments in this case were identical except for gear ratio.

Test "A" was made with a slow-speed gearing, while test "B" was made with a higher speed gearing. A comparison of the service conditions shows that they were approximately the same, the slightly higher schedule speed in test "B" being balanced by the somewhat fewer stops and slow-downs, shorter duration of stop and decreased average passenger load. The railway company had in service a number of cars equipped as for test "B." The car geared as for test "A" was operated in regular service for a considerable period of time prior to the tests and proved itself capable of maintaining the schedule equally as well as the car geared for higher speed.

It will be noted that not only did the tests show that the low-speed gearing effected a saving of 13.8 per cent in the power consumption but they also showed that, whereas the equipments with the high-speed gearing were operating with dangerous temperature rise, with the low-speed gearing the heating of the motors was just within safe limits. All equipments of these same motors installed since these tests were made, have been provided with the low-speed gears.

In Volume 29, page 1484, of the A. I. E. E. Transactions, Mr. H. St. Clair Putnam makes the following statement regarding the use of coasting clocks on the Manhattan Elevated Railway in New York:

"The result of these calculations and tests shows that an increase in the percentage of coasting from 12 per cent to 37.5 per cent will effect a saving of 24 per cent in the power required for traction."

The report of tests, made on cars of the Chicago Railway Company, as given in the *Electric Railway Journal*, Volume 38, pages 1192 and 1200, shows that increasing the accelerating and braking rates (through the use

Table I

Motor Type	Light Weight	Standard	Field Control	Light Weight	Standard	Field Control
Length of run—feet	587	587	587	1056	1056	1056
Time of run—seconds	43.4	43.4	43.4	61	61	61
Stops per mile	9	9	9	5	5	5
Length of stop—seconds	7	7	7	7	7	7
Scheduled speed—m.p.h.	9.2	9.2	9.2	11.8	11.8	11.8
Braking rate—m.p.h.p.s.	1.25	1.25	1.25	1.25	1.25	1.25
Motor equipment	4-40 h.p.	4-40 h.p.	4-40 h.p.	4-40 h.p.	4-40 h.p.	4-40 h.p.
Gear ratio—33-in. wheels	5.12	5.12	5.12	5.12	5.12	5.12
Motor r.p.m. at 40 h.p. at 500 volts	608	526	445	608	526	445
Amperes at full load of motor	72	72	73	72	72	73
Car weight, equipped and loaded—tons	29	30	30	29	30	30
Accelerating current—amperes per motor	75	75	68.5	75	75	68.5
Accelerating rate—m.p.h.p.s.	1.5	1.88	1.88	1.5	1.88	1.88
Speed at which rheostats are all out	12.4	9.9	8.9	12.4	9.9	8.9
Coasting time—seconds	7.5	7.5	10.8	19.8	13.3	20.8
Speed at time brakes are applied—m.p.h.	16.2	15	14.5	15.3	16	14.7
Watt.-hr. per ton-mile	145	125	113	99.3	96.7	85.7
Sq. rt. mn. sq. amp. per motor	38.3	33.3	32.4	33.9	30.4	29.7
Temp. rise in service from air 25 degrees C.	65	47	45	50	42	40
Kw.-hr. per car-mile	4.21	3.75	3.39	2.88	2.90	2.57

Table II

Motor Type	Standard	Field Control	Standard	Standard	Field Control	Standard
Length of run—miles	1	1	1	6	6	6
Time of run—seconds	150	150	150	611.8	563	563
Length of stop—seconds	12.5	12.5	12.5	60	60	60
Schedule speed—m.p.h.	24	24	24	35.3	38.4	38.4
Accelerating rate—m.p.h.p.s.	1.25	1.25	1.25	1.25	1.25	1.25
Braking rate—m.p.h.p.s.	1.25	1.25	1.25	1.25	1.25	1.25
Motor equipment	4-75 h.p.	4-75 h.p.	4-90 h.p.	4-75 h.p.	4-75 h.p.	4-90 h.p.
Amperes at full load of motor	130	130	156	130	130	156
Car weight, equipped and loaded—tons	38	38	39.5	38	38	39.5
Accelerating current—amperes per motor	127	122	177.5	127	122	177.5
Speed at which rheostats are all out—m.p.h.	21.3	20.3	28.2	21.3	20.3	28.2
Coasting time—seconds	60	70	77.5	67.8	86.2	86.7
Speed at which brakes are applied	27.1	26	25.7	30	30	30
Kw-hr. per car-mile	2.4	2.27	2.70	2.025	2.11	2.39
Watt-hr. per ton-mile	63.2	59.7	68.4	53.4	55.5	60.5
Temp. rise in service from air 25 degrees C.	58°C.	60°C.	70°C.	50°C.	58°C.	60°C.

of coasting clocks) will save 15.6 per cent of the power required for traction without special effort on the part of the motorman, and that it is possible and practicable to increase this saving to 27 per cent. This report also shows that there is a saving in brake shoes amounting to 40.8 per cent.

Both of the above reports show what can be accomplished by correct operation as induced by the application of coasting time recorders. It should be noted in connection with the Chicago Railway Company service that the equipments now maintain the schedule so easily that the gearing is being changed from 4.06 to 4.73 in order to reduce the peak demands. Incidentally it may be noted that one of the dangers previously mentioned in connection with the application of coasting clocks is beginning to show itself here, as the Chicago report states that the running time for the cars on the line tested has been reduced 3 minutes. In any such case, care should be exercised to determine what effect upon the heating of the motors such a reduction in running time may produce before faster schedules are adopted generally. More or less protection against too rapid acceleration may be secured by careful circuit-breaker adjustments or automatic acceleration, or by a graduated scale with respect to the bonus offered motormen in connection with their coasting time records.

Table III

Tests in New York Showing Effect of Gear Ratio and Field Control on Power Consumption

Test Number	Weight of Loaded Car, Tons	Motor	Rev. Per. Min. 40 H.P.	Gear Ratio	Stops Per Mile	Slow-Downs Per Mile	Average Length of Stop, Seconds	Schedule Speed, Miles Per Hour	Average Volts	Watt-Hr. Per Ton-Mile
1	20.214	Standard 60 h.p.	560	4.6	6.975	2.86	8.503	7.126	557	152.26
*2	19.729	Standard 40 h.p.	550	5.12	6.778	3.08	7.765	7.261	556	141.63
†3	20.153	Field Control 40 h.p.	445	5.12	8.333	3.11	7.240	7.142	551	133.85
4	19.714	Field Control 40 h.p.	445	5.12	6.881	3.56	7.335	7.409	555	124.41

2—Saves 7 per cent of power used by 1. Reason—12 per cent less car speed at 40 h.p.
3—Saves 5.5 per cent of power used by 2. Reason—field control.
4—Saves 7 per cent of power used by 3. Reason—fewer stops.
4—Saves 12 per cent of power used by 2. Reason—field control.
*Normal field on field control motor.
†In congested district ran in series only.

Table IV

Tests on Frankstown Avenue

(Line of Pittsburgh Railways Company)

Showing Effect of Gear Ratio on Power Consumption and Motor Heating

Items	A	B
Weight of motor car without load—pounds	49000	49000
Weight of trailer car without load—pounds	23000	23000
Motors	4-50 h.p.	4-50 h.p.
Gear ratio—33-inch wheels	4.6	3.67
Schedule speed—m.p.h	9.15	9.50
Stops per mile	8.7	8.63
Slow-downs per mile	1.94	1.37
Average duration of stops—seconds	6.8	6.2
Average passenger load	37	30
Average voltage	483	480
Watt-hours per ton-mile	137	159
Average temperature rise on armatures corrected to 25 degrees air temperature—degrees Centrigrade	68.8	87.8

"A" saves 13.8 per cent of the power used by "B." Reason—correct gearing.

Day's service consisted in each case of two round trips with trailer, then three round trips without trailer, followed by two round trips with trailer.

Table III shows the result of a series of tests made on the cars of the Metropolitan Street Railway Company of New York under the direction of Mr. H. H. Adams. It will be seen from this table by comparing tests 1 and 2 that the use of a slower speed armature and greater gear reduction effected a power saving of 7 per cent. In test 3, throughout the congested district the equipments were operated in series only and then operated in series and parallel on the remainder of the runs. In spite of the fact that this test shows nearly 23 per cent more stops than test 2, the power consumption was decreased 5.5 per cent due to the use of field control.

In test 4 the number of stops and other service conditions are practically the same as in tests 1 and 2 but the motors were operated making full use of the field control in series and parallel over the entire line. This test showed 7 per cent less power consumption than test 3 with its greater number of stops and 12 per cent saving in power in comparison with test 2, where the service conditions were practically the same. Substantially all of this saving was due to the use of the field control motor in test 4 as against the non-field control motor in test 2. In this connection, it should be noted that while the 60-horsepower motors of test 1 showed an average temperature rise of about 48 degrees Centigrade corrected to air at 25 degrees Centigrade, the 40-horsepower motors in test 4 showed only 58 degrees Centrigrade temperature rise, which is still a perfectly safe operating condition.

Tests recently made on various lines of the Pacific Electric Railway showed an average power consumption of 97.3 watt-hours per ton-mile with quadruple 75-horsepower, 650-revolutions-per-minute motors geared 2.18:1. Other 75-horsepower, 640-revolutions-per-minute motors geared 3.24:1 showed an average power consumption of 87 watt-hours per ton-mile.

The latter motor with field control showed an average power consumption of 81 watt-hours per ton-mile.

These figures indicate that proper gearing would effect a power saving of 10.6 per cent in this service, while the application of field control would produce a further saving of about 6.9 per cent and the total saving which could be obtained by the use of correct gearing in combination with field control will be about 16.8 per cent.

It is interesting to note further in this connection that the average temperature rise of the motors, corrected to air at 25 degrees Centigrade, in the most severe service was 80.5 degrees Centigrade for the motors geared for high speed and 51.2 degrees Centigrade for the field control motors. Temperatures on the non-field control motor geared for low speed in this service are not available at the present time.

Summing up the results of calculations and tests as previously described in detail, it is found that proper gearing and armature speed, correct operation and field control, are essential to the most economical operation of railway service and the indications are that from 10 per cent to 30 per cent of the power now consumed in specific cases may be saved by a careful study of the operating conditions and the intelligent application of these principles.

Chapter Five

Car Operation Efficiency—with Special Reference to Energy-Input Method of Determining Motormen's Efficiency

Chapter Five

Car Operation Efficiency

With Special Reference to Energy-Input Method of Determining Motormen's Efficiency

By C. C. CHAPPELLE

Consulting Engineer and Vice-President
The Railway Improvement Company

THE Feb. 19, 1916, issue of the *Electric Railway Journal*, contained a communication from Mr. C. H. Koehler, commenting on the writer's article, "Fundamental Principles of Car Operation Efficiency" appearing in Jan. 15, 1916, issue of the *Electric Railway Journal*, which article is Chapter Two of this volume.

Mr. Koehler's criticisms may suggest to some readers that the general fundamental principles (Chapter Two) are not applicable and controlling for the attainment of efficiency under practical operating conditions.

The analysis of the fundamental principles discussed in Chapter Two, hereof, covers the principles involved for the attainment of efficiency and was made without any thought or intention of "several misleading comparisons made of two devices now on the market for determining motormen's efficiencies, etc." that it appears has been interpreted therefrom.

The solution of the efficiency problems confronting electric railways, must ultimately be squarely met and solved by the effective practical application of the fundamental principles.

With the view of furthering a better understanding of such principles we will dignify Mr. Koehler's critical comments by showing their relations to both principles and practice.

The Efficiency Problem

The efficiency problem is not one of controversy as to methods, but is one involving the consideration and analysis of principles and factors definitely determining and controlling the limitations of attainable efficiency for the given traffic conditions.

Power reduction is one of the results obtained by better efficiency in operation. The fundamental principles demonstrate that power input, for given equipment and traffic conditions, is determined and controlled by certain factors, some of which are entirely, some partially and others not at all under the control of the motorman.

The adaptability of methods for checking efficiency in the use of power must be considered from the standpoint of whether checking the *result* (power input at the car) or checking the factors controlling and determining such result is most effective to secure the attainable efficiency.

Some undoubtedly believe checking the *result* is the preferable system and Mr. Koehler's criticism being from such viewpoint, it becomes desirable to analyze somewhat in detail his suggestions and show their relations to the general principles.

Practical Principles and Law of Averages

The first practical principle that Mr. Koehler overlooks is that the manufacturer and the user of motor equipment select equipment and gear ratio suitable for operation with the motors in multiple for the normal average traffic conditions. The second principle is the basis for the application of the "law of averages." The writer's article of Jan. 15, 1916 (Chapter Two), applies the law of averages, based on the averages encountered in practical operations in reference to well-known variations in certain factors recognized as affecting practical operating results. These averages were analyzed by the well-known and recognized accurate method of plotting speed-time and power diagrams based on the characteristic performance curves for the motor equipment. Such analyses and the conclusions therefrom as to the fundamental principles and factors controlling and limiting attainable efficiencies and the effective manner to secure such efficiencies, are based on multiple operation of the equipment, because, as before stated, multiple is the normal operation contemplated by both the manufacturer and user of the equipment, as suiting the average conditions predominating for the aggregate operations encountered in regular operating practice.

Every practical operator knows that the length of a one-way trip on the average railway route is anywhere from 2 miles to 10 miles, depending upon the layout of the city and the plan of routing. Probably 4 miles to 5 miles approximates the average length for the typical one-way trip of the average railway. For example, the average equivalent number of stops per mile on the Madison Avenue line (Chicago Surface Lines), having one terminus in the congested loop district, has been found to be approximately nine stops per mile.

The writer's article of Jan. 15, 1916, states that the car and equipment selected by Mr. Koehler as the basis for his "example" is used on a typical line of a well-known company having an average equivalent of five stops per mile. An average equivalent of seven and one-half stops per mile approximates the typical conditions on the average railway route.

With equipment selected for normal operation in multiple, at the schedule speeds usually encountered upon any given route in connection with the equivalent average number of stops thereon, short runs are encountered between stops (particularly in the congested district of the traffic terminus), for which, if normal multiple operation is followed, the controller must be thrown off at or near full multiple position. For such short runs the rheostatic losses from full series to full multiple position are so great relatively that a saving in power will result if such a short run is made in full series without attempting the normal multiple operation.

Between the normal mode of multiple operation and the series operation, which is advantageous under certain conditions of congested traffic, an intermediate mode of operation is possible, *i.e.*, pausing a few seconds in series position then notching up to full multiple. Such operation follows the governing laws of the fundamental principles. Its use under the predominating railway conditions that contemplate multiple operation will show a loss, as in reality it is only an equivalent average lower rate of acceleration. Under the rather infrequent traffic conditions where advantages of series operation are relatively small compared with multiple operation, pausing on the series position of the controller obviously possesses advantages.

Practical operating results, however, demonstrate that best results are obtained with few and simple rules for the direction of the motorman. The conditions for the aggregate of operations and the selected equipment contemplates multiple operation, as before stated. Increase in the rates of acceleration and braking within the limitation of the equipment and the comfort of the passengers result in increased coasting and corresponding reduction in power for the equipment operated at the schedule speeds and traffic conditions encountered under the average conditions of railway operations. Therefore, pausing on the series position of the controller should be discouraged to obtain the best efficiency in practical operation.

The foregoing mentioned series operation and pausing on series position of controller seems to be the basis of Mr. Koehler's discovery, and upon which he builds his "example" in connection with which is mentioned the old gastronomical adage, "The proof of the pudding is in the eating." Having selected such an isolated example based on his Cycle I run, equivalent to over twenty stops per mile, Mr. Koehler proceeds to wreck the entire basis of the fundamental principles involved in car operation efficiency, and thereby demonstrates that the writer's "conclusions must have been based on unsound premises"!

Mr. Koehler has outlined clearly the basis of his proposed proper method of operation,

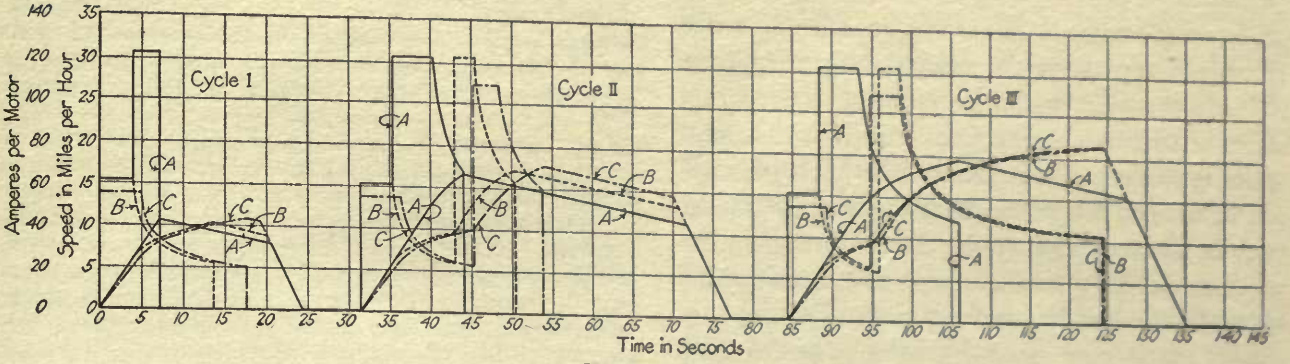


Figure 1-B

Operating Data Graphs for Typical Runs of Different Lengths

and it is easy to show a little further the application of his principles to the reasonable limitations of traffic conditions encountered in ordinary every-day average practical operations.

In the accompanying Fig. 1-B we have shown the application of Mr. Koehler's principles and selected equipment in three sets of diagrams. Cycles I and II are Mr. Koehler's corresponding runs of one block and three blocks respectively, making his total run of four blocks, with an average of ten stops per mile for a run of 0.2 mile, or a distance approximately only 5 per cent of the average one-way trip. For these runs he has assumed an average number of stops 11 per cent higher than upon one of the most congested lines of Chicago, 33⅓ per cent higher than the average number of stops hereinbefore mentioned as typical of the average railway line, and just double the number of stops mentioned as the average for the particular equipment on the line of Company B in the writer's article of Jan. 15.

We do not contemplate dragging the reader through a series of diagrams for the entire length of the average typical line route, but we have in Cycle III one additional run of only four blocks, to be made immediately following Mr. Koehler's Cycles I and II. Such a run is certainly well within the reasonable practical probabilities, for Cycles, I, II and III aggregate only a total run of 0.4 mile or approximately 10 per cent of the average one-way trip. In connection with such a short total run the equivalent average number of stops is seven and one-half per mile, or approximately that encountered in average practice.

In Table I-B is shown a summary of the data for diagrams A, B and C of Cycles I, II and III (Fig. 1-B), also for the total run composed of Cycles I and II and the total run composed of Cycles I, II and III. The diagrams A represent the performance of Mr. Koehler's Motorman A defined as "after a coasting record." Diagrams B represent the performance of his Motorman B, represented as having definite anticipatory knowledge in reference to the

Table I-B

SUMMARY OF DATA FOR DIAGRAMS SHOWN FOR CYCLES I, II AND III

	Cycle I	Cycle II	Cycle III	Total run, Composed of Cycles I and II	Total run, Composed of Cycles I, II and III
Length of run—feet..........	259	791	1,062	1,050	2,112
Corresponding number stops per mile	20.38	6.68	4.97	10.06	7.5
Acceleration—A and B, m.p.h.-p.s.	1.5	1.5	1.5	1.5	1.5
Acceleration, C, m.p.h.p.s.....	1.25	1.25	1.25	1.25	1.25
Schedule Time A, B and C—7 stops 1 mile..............	31.40	53.0	57.85	84.40	142.25
Schedule speed A, B and C—m.p.h.	5.62	10.16	12.50	8.48	10.12
Seconds coasting—A	13.3	27.6	21.50	40.9	62.4
Seconds coasting—B	6.3	20.4	....	26.7	26.7
Seconds coasting—C	1.5	16.2	....	17.7	17.7
Per cent coasting—A	42.35	52.10	37.17	48.43	43.85
Per cent coasting—B	20.04	38.50	....	31.63	18.76
Per cent coasting—C	4.78	30.58	....	20.97	12.44
Ampere seconds—A	641	1,183	1,720	1,824	3,544
Ampere seconds—B	540	1,205	2,240	1,745	3,985
Ampere seconds—C	627	1,303	2,270	1,930	4,200
Kilowatt-hours per car-mile—A	3.623	2.193	2.376	2.550	2.460
Kilowatt-hours per car-mile—B	3.053	2.232	3.093	2.440	2.767
Kilowatt-hours per car-mile—C	3.543	2.416	3.135	2.698	2.915
Increase in per cent coasting A over per cent coasting B....	22.34	13.60	37.17	16.80	25.09
Per cent saving-power for A over B referred to power for A	—15.72	17.8	30.3	—4.32	12.47
Increase in per cent coasting A over per cent coasting C....	37.57	21.52	37.17	27.46	31.41
Per cent saving-power for A over C referred to power for A	—2.21	10.17	31.9	5.81	18.46

Note (Mode of Operation)

Motorman A—Normal operation, straight up to multiple—acceleration 1.5 m.p.h.p.s.
Motorman B—Series operation, or pausing in series for a few seconds—acceleration 1.5 m.p.h.p.s.
Motorman C—Series operation, or pausing in series for a few seconds—acceleration 1.25 m.p.h.p.s.
Braking rate for A, B and C = 2 m.p.h.p.s.
Train and coasting resistance 20 lb. per ton

The above results show that for schedule speed approximating the conditions of operation for which a given motor equipment of given gear ratio is selected by the user and manufacturer, the practice of pausing on series position of controller in expectation of stop bell is wrong when considered in its relation to the entire trip run, for the diagrams prove that even over a distance of only 0.4 mile such operation of the controller requires from 12 per cent to 18 per cent more power than the normal operation of notching up straight into multiple.

stop requirements of traffic conditions; diagrams C represent the performance of a third Motorman C, whom we have taken the liberty of introducing and who has the same anticipatory powers claimed for Motorman B. Motorman C has noted from watching a certain device "placed in view of the motorman" that the amperes drawn during the acceleration period is less if he accelerate at 1.25 miles per hour per second instead of the wasteful rush of amperes which he has observed when using the accelerating rate of 1½ miles per hour per second of diagrams A and B.

It is to be noted that the results for diagrams A and B, Cycles I and II, and for the total run composed of Cycles I and II, are somewhat different from the results of Mr. Koehler's similar diagrams, which we have endeavored to reproduce from the data of his article, Motorman A being even more wasteful than found by Mr. Koehler for Cycle I, and somewhat improved in Cycle II, and the total run composed of Cycles I and II. Table I-B, however, gives the complete data, whereby anyone desiring can check any discrepancies in the results by constructing the speed-time and power diagrams.

The diagrams have been constructed using Mr. Koehler's suggested retarding force of 20 lbs. per ton for train and coasting resistance instead of that used in the writer's former article (Chapter Two) for, as commented by Mr. W. B. Potter in his communication (*Electric Railway Journal*, Jan. 29, 1916), such modification does not "detract from the general conclusions of the article."

Motormen's Operations by Diagram

The reasonableness and simplicity of diagrams applied to practical operations, as also the unreasonableness of befogging general principles and practice by a strained special example, will be apparent from the consideration of the detailed operations of Motormen A, B and C, as shown from the diagrams of Fig. I-B and Table I-B, as follows:

For Cycle I (run of only one block of 259 ft.) the factors are as follows:

Motorman A, following the mode of normal operation contemplated in the selection of the equipment as suiting the average traffic conditions, notches straight up to multiple at the rate of 1.5 miles per hour per second, gets bell to stop in 7.2 seconds after starting, throws off power, coasts 13.3 seconds and brakes at the rate of 2 miles per hour per second and makes a 7-second stop at the end of the first block.

Motorman B accelerates to the series position of the controller at a rate of 1.5 miles per hour per second, but in anticipation of a stop or from general sluggishness pauses on the series position, gets bell to stop 7.2 seconds after starting, continues in series until 13.6 seconds from starting, throws off power, coasts 6.3 seconds, brakes at rate of 2 miles per hour per second and makes a 7-second stop at the end of the first block.

Motorman C, in anticipation of a stop or from a wrong conception of the relation of amperes observed as required for different rates of acceleration, or from being even a little more sluggish by nature than B, accelerates to the series position of the controller at the rate of 1.25 miles per hour per second, pauses on the series position, gets bell to stop 7.2 seconds after starting, continues in series until 17.6 seconds from starting (in order to make the schedule), throws off power, coasts 1.5 seconds, brakes at the rate of 2 miles per hour per second and makes a 7-second stop at the end of the first block.

For Cycle II (run of three blocks, totaling 791 ft.) the factors are as follows:

Motorman A accelerates in the manner and for the reasons outlined for Cycle I to full multiple, continues in multiple until he attains the speed which his experience and judgment have established as suitable for the probable traffic conditions considered in relation to the time-element factors controlling his ultimate efficiency, with maintenance of schedule, then throws off power, coasts 27.6 seconds, brakes at 2 miles per hour per second and makes the 7-second stop called for the end of the third block of this three-block run.

Motorman B accelerates in the manner and for the reasons outlined for Cycle I to the series position, pauses on the series position 7.5 seconds (for the bell that came not), then passes to multiple and continues in multiple a sufficient time to make up for the delay caused by pausing on series with maintenance of schedule, then coasts 20.4 seconds, brakes at 2 miles per hour per second and makes the 7-second stop called for the end of the third block of this three-block run.

Motorman C accelerates, in the manner and for the reasons outlined for Cycle I, to the series position, pauses on the series position 8.8 seconds (for the bell that came not), then passes to multiple and continues in multiple a sufficient time to make up for his delays caused by slow acceleration and pausing on series, with maintenance of schedule, then coasts 16.2 seconds, brakes at 2 miles per hour per second and makes the 7-second stop called for end of third block of this three-block run.

For Cycle III (run of four blocks, totaling 1056 ft.) the factors are as follows:

Motorman A accelerates, in the manner and for the reasons previously described, to full multiple, continues in multiple until he has attained the speed his experience and judgment have established as suitable for the probable traffic conditions considered in relation to the time-element factors controlling his ultimate efficiency with maintenance of schedule, then throws off power, coasts 21.5 seconds, brakes at 2 miles per hour per second and makes the 7-second stop called for at the end of the fourth block of this four-block run.

Motorman B accelerates, in the manner and for the reasons previously described, to the series position, pauses on the series position 7.5 seconds (for the bell that came not), then passes to multiple, but the habit based on the wrong principles for normal operation has caused so much delay in time that to maintain schedule power must be applied (resulting in no coasting) until the application of the braking rate of 2 miles per hour per second to make the 7-second stop called for the end of the fourth block of this four-block run.

Motorman C follows his previously described usual mode of accelerating to and pausing on series position, but, knowing that his efforts to keep down the rush of amperes during acceleration sometimes gets him behind the schedule, his judgment gives him a "hunch" and he pauses this time on series only 6.6 seconds (for the bell that came not), then continues into multiple, but he, too, is a victim of the wrong habit of operation for efficiency under normal operations, and using 2 miles per hour per second braking, completes this four-block run with no coasting, in order to maintain the schedule, the duration of stop is 7 seconds as before.

In Table I-B, column headed "Total run composed of Cycles I, II and III," there are tabulated the essential factors of the operations and results of Motormen A, B and C for this total run aggregating 0.4 mile, or approximately 10 per cent of the length of a one-way trip of a typical average car line route.

It is interesting to note that even for this short run the ratio of the increase in per cent coasting to the resulting per cent saving in power of A and B operations gives a ratio of 1 to 0.51, and similarly for A and C operations, the ratio of 1 to 0.59, being a definite illustration of the definite ratio existing between increase in per cent coasting to per cent saving in power that the fundamental principles establish as existing in connection with conditions encountered in practical operation. Such ratios are somewhat reduced for the particular comparisons, due to the Cycle I run, for which series operation, only, is advantageous.

Practical Limitations Control

In the foregoing analysis we are conceding and applying for comparison the exact principles of operation suggested by Mr. Koehler. Every practical operator knows that regardless of the use or non-use of any efficiency-checking device, other limitations control the operations of the motormen in congested districts of the general nature illustrated in Cycle I, and, therefore, that the motorman rarely attempts multiple operation under such conditions. The need is apparent, however, that under such congested conditions (where series operation is the practice of motormen) the importance of the time element should be impressed on the motormen and checked for proper results under such congested conditions, as is apparent from consideration of the relative operations of Motormen B and C illustrated in Cycle I, Fig. I-B and Table I-B, hereof.

Coasting Correct and Simple Check

We will not take space discussing in detail Mr. Koehler's comments on the principles discussed and applied under the sub-sections, "Energy Input a Misleading Measure of Efficiency" and "Coasting a Correct Relative Measure of Actual Efficiency," of pages 35 and 37, Chapter Two, hereof. We leave to the reader the logic and correctness of the principles and the application thereof which are outlined in such sub-sections. The logic of Mr. Koehler's reasoning is on parity with that in recent printed matter for which Mr. Koehler's company is responsible; in one installment the term "cannon-ball" acceleration" is used in referring to the increase of the acceleration rate toward the maximum within the limits of equipment and comfort of passengers, while in the next installment is an illustration of *rapid* acceleration on a 1000-ft. run effecting a saving of 27.3 per cent in power.

The schedule speeds and stops per mile, for which 40 per cent resulting coasting was shown with the widely varying ranges of kilowatt-hours input at the car enumerated, closely approximate the actual conditions existing on a certain line of a well-known railway on which the daily services of some sixty-four different motormen are required. On this line 40 per cent more cars are required for the evening rush hours than for the morning rush hours, and the number is nearly four times greater than that required at medium schedule for the service between the morning and evening rush hours. The night service, with its smaller

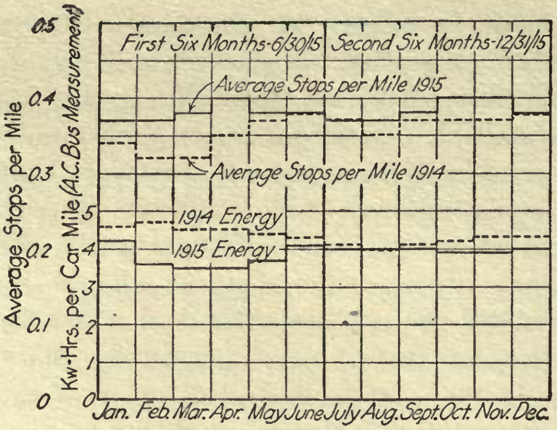


Figure 2-B

Energy Consumption Data Graphs for Annapolis Short Line

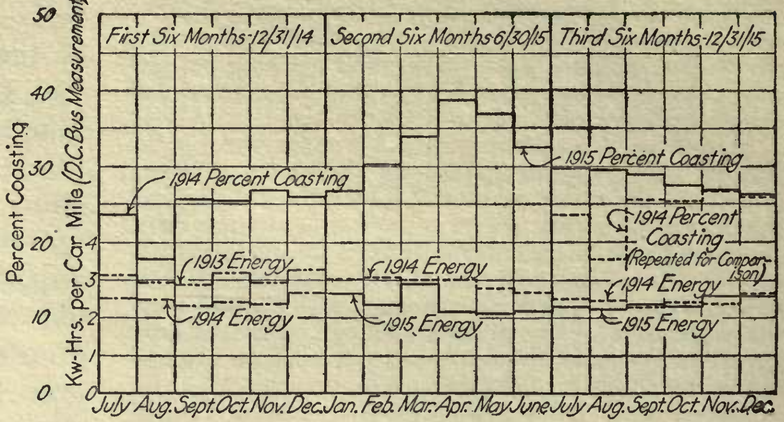


Figure 3-B

Energy Consumption Data Graphs for Cleburne Interurban Line

number of cars, approximates the highest schedule speed.

The classifying and subdividing necessary to equitably compare the sixty-four motormen on such line may be the simple matter that Mr. Koehler suggests, but we submit that the 40 per cent coasting shown as being the measure of their efficiency for the particular conditions existing, will appeal to the practical operator.

Operation Results Confirm Principles

Fortunately, practical results are available from recent periodicals confirming the correctness of the conclusions established from the fundamental principles involved in car operation efficiency. The Feb. 26, 1916, issue of the *Electric Railway Journal* contains an admirable article by D. E. Crouse, entitled "Ampere-Hour Meters on the Annapolis Short Line." Without any desire to detract from the value of Mr. Crouse's article, we have sub-divided his first-year comparative results from the use of meters into two periods, *i.e.*, the first six months' use, ended June 30, 1915, and the second six months' use, ended Dec. 31, 1915. Table II-B and Fig. 2-B show the comparative results (based on a.c. bus measurement) for the respective first and second six-month periods in tabular and graphical form.

The Stone & Webster *Public Service Journal*, January, 1916, issue, contains an article by R. E. Griffiths, entitled "The Coasting Time Recorder and Its Operation." From the data in Mr. Griffiths' article we have prepared Table III-B and Fig. 3-B, showing the comparative results (based on d.c. bus measurement) on the Cleburne interurban line of the Tarrant County Traction Company for the first eighteen months' operation of Rico Coasting Recorders ended Dec. 31, 1915, the eighteen-month period being divided into first, second and third six-month periods of comparative operation.

Tables II-B and III-B and Figs. 2-B and 3-B show results obtained in practical operation under somewhat similar conditions, *i.e.*, interurban service, which approaches more nearly uniform conditions for schedule speed, number and duration of stops, etc., than can possibly exist for ordinary street railway service.

Table II-B and Fig. 2-B show for the Annapolis Short Line a saving in power of 16.4 per cent from the first six months' use of meters compared with the corresponding period of the previous year. The average number of stops per mile was 0.04 greater for the meter period. Mr. Crouse states in his article that the work done is indicated by the relative relation of the average number of stops per mile. Similarly, Table II-B and Fig. 2-B show a saving in power of only 4.7 per cent for the second six months' use of the meters, although the comparative average number of stops per mile increased only 0.01 stop per mile.

Table III-B and Fig. 3-B show for the Cleburne interurban line a saving in power of 19.6 per cent, with average of 24.2 per cent coasting for the first six months' use of coasting recorders, compared with the corresponding period of the previous year. Similarly (see Table III-B and Fig. 3-B), there was a saving in power of 18.7 per cent, with an average of 33.1 per cent coasting, for the second six months' use of the recorders for the comparative periods and (see Table III-B, Fig. 3-B) the third six months' use, which covers comparative periods with the coasting recorders in use, shows saving in power for the comparative periods of 2.8 per cent, with an increase in coasting from 24.2 per cent to 28.1 per cent.

The interesting feature of the cited data is that the saving in power on the Annapolis Short Line from the use of meters dropped from 16.4 per cent average saving for the first six months to only 4.7 per cent average saving for the second six months' use of the meters, although the comparative traffic conditions were easier, based on the comparative increase in the average stops for the latter period.

On the other hand, the savings in power on the Cleburne interurban line for the first six months' use of recorders was 19.6 per cent, for the second six months 18.7 per cent, and for the third six months 2.8 per cent increase, compared with the results of the first six months' use, notwithstanding the gross earnings per car-mile (another accurate measure of work done), we are advised, showed more than 6 per cent increase.

Mr. Crouse's account of the method of operating the meters indicates high-grade care and attention to secure best results, particular attention being given to providing, as far as possible, for the effects of variations in the time-element factors affecting the results.

The foregoing actual results confirm what the fundamental principles clearly indicate, namely, that the measurement of power input only is a misleading and ineffective measure of efficiency, that records of such measurement mean nothing unless analyzed in reference to the component time-element factors, and that, analyzed or unanalyzed, such measurement records lead ultimately to the bewilderment and discouragement of the motorman, the human factor through which results are obtained.

The Annapolis Short Line secured for its second six months' comparative use of the meters, approximately the results ultimately obtained by such more or less indirect methods for checking the efficiency of the motormen. It would have been interesting to see the results had the Annapolis Short Line approached the efficiency problem with the Rico Coasting Recorder. The fundamental principles indicate that their attainable efficiency, showing 16.4 per cent saving in power, would have been maintained, and this is confirmed by the results on the Cleburne interurban line.

Table II-B

COMPARATIVE ENERGY PER CAR-MILE AND AVERAGE STOPS PER MILE FOR ANNAPOLIS SHORT LINE, FOR SIX MONTHS ENDED JUNE 30, 1915, JUNE 30, 1914; ALSO, FOR SIX MONTHS ENDED DEC. 31, 1915, AND DEC. 31, 1914

First Six Months Using Meters Ended June 30, 1915

	Kw.-Hr. per Car-Mile, 1915	Kw.-Hr. per Car-Mile, 1914	Per Cent Saving in Power by Use of Ampere Meters	Average Number Stops per Mile for 1915	Average Number Stops per Mile for 1914	Increase in Average Number Stops for 1915
January	4.2	4.6	8.7	0.37	0.34	0.03
February ..	3.6	4.7	23.4	0.37	0.32	0.05
March	3.5	4.5	22.2	0.38	0.32	0.06
April	3.5	4.5	22.2	0.40	0.35	0.05
May	3.7	4.4	15.9	0.38	0.37	0.01
June	4.1	4.3	4.6	0.38	0.38	0.00
Average	3.76	4.50	16.4	0.38	0.34	0.04

Second Six Months Using Meters Ended Dec. 31, 1915

	Kw.-Hr. per Car-Mile, 1915	Kw.-Hr. per Car-Mile, 1914	Per Cent Saving in Power by Use of Ampere Meters	Average Number Stops per Mile for 1915	Average Number Stops per Mile for 1914	Increase in Average Number Stops for 1915
July	4.0	4.1	2.4	0.37	0.37	0.00
August	4.0	4.0	0.0	0.37	0.35	0.02
September ..	4.0	4.1	2.4	0.38	0.37	0.01
October	3.9	4.2	7.1	0.40	0.37	0.03
November ..	3.9	4.3	9.3	0.40	0.37	0.03
December ..	4.0	4.3	7.0	0.38	0.38	0.00
Average	3.96	4.16	4.7	0.38	6.37	0.01

Table III-B

COMPARATIVE ENERGY PER CAR-MILE AND PER CENT COASTING, FOR CLEBURNE INTERURBAN LINE, FOR SIX MONTHS ENDED DEC. 31, 1914, AND DEC. 31, 1913; ALSO FOR SIX MONTHS ENDED JUNE 30, 1915, AND JUNE 30, 1914, AND FOR SIX MONTHS ENDED DEC. 31, 1915, AND DEC. 31, 1914

First Six Months Using Coasting Recorders Ended Dec. 31, 1914

	Kw.-Hr. per Car-Mile, 1914	Kw.-Hr. per Car-Mile, 1913	Per Cent Saving in Power by Use of Recorders	Average Per Cent Coasting, 1914	Average Per Cent Coasting, 1913
July	2.50	3.11	19.6	23.7	Operation with coasting recorders began July, 1914
August	2.49	2.92	14.4	17.8	
September	2.30	2.88	17.4	25.7	
October	2.40	3.19	24.7	25.5	
November	2.38	2.94	19.1	26.8	
December	2.66	3.25	18.2	26.0	
Average	2.45	3.05	19.6	24.2	

Second Six Months Using Coasting Recorders Ended June 30, 1915

	1915	1914		1915	1914
January	2.65	3.06	13.4	26.7	Operation with coasting recorders began July, 1914
February	2.33	3.09	24.6	30.3	
March	2.90	3.03	4.3	33.9	
April	2.16	3.01	28.2	38.2	
May	2.13	2.79	23.6	37.0	
June	2.19	2.68	18.3	32.6	
Average	2.39	2.94	18.7	33.1	

Third Six Months Using Coasting Recorders Ended Dec. 31, 1915
(Comparison of Coasting Recorder with Coasting Recorders)

	1915	1914		1915	1914
July	2.30	2.50	8.0	29.8	23.7
August	2.25	2.49	9.6	28.7	17.8
September	2.28	2.30	0.9	29.0	25.7
October	2.32	2.40	3.3	27.6	25.5
November	2.59	2.38	8.1*	26.9	26.8
December	2.58	2.66	3.0	26.3	26.0
Average	2.38†	2.45	2.8	28.1	24.2

---

*Increase.

†This is 21.9 per cent saving in power over the corresponding 6 months of 1913 operation without coasting recorders.

Finale

THE foregoing discussions demonstrate that there is no reason to assume the efficiency of a car's operations is something that cannot be accurately measured and automatically recorded.

Since the importance of efficiency in car operation is disputed by none, the means for accurately measuring and recording the degree of that efficiency should be conscientiously studied by every electric railway executive and operating staff, to the end of achieving and retaining the highest efficiency attainable for the conditions of equipment and traffic.

The most effective means to secure that end are the RICO Coasting Recorder and the RICO C & S Recorder equipments developed by this company, as daily demonstrated under the widest conceivable ranges of electric railway operation.

Railway Improvement Company
61 Broadway, New York