American Railway Signaling Principles and Practices

CHAPTER III

Principles and Economics of Signaling

Published by the Signal Section, A. A. R.
59 East Van Buren Street, Chicago 5, Ill.

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Preface

Signal engineering has developed greatly and rapidly from early times, when its primary function was to provide safety, to the present time when, in addition to safety, signal systems are important operating methods for increasing the traffic capacity of a line, increasing the utilization of the physical plant, expediting train movements, etc., and, as such, are of recognized economic value.

While some of the modern signal systems, such as relay type interlockings, classification yard car retarder systems, and traffic control systems, when under contemplation at a specific location under specific circumstances will be necessary and justified either as an expediency or for certain reasons obvious to all concerned, there are many times when the justification for the expenditure is not so self-evident. Consequently, there is a need for forecasting the economic results that might be obtained on a specific territory by the installation of one of the various signal systems, with or without associated track changes, improved motive power, changes in traffic, etc., and proving the economic value of a proposition.

This chapter has been prepared to fill the need for an authoritative reference work, and to condense and rearrange in convenient form previously published material in order that it may serve as a guide to the type and application of signaling which may be expected to handle the volume of traffic with safety and produce the largest economic return on the investment.

In this chapter will be found detail description on how to prepare working charts which facilitate the determination of the changes in the desired elements of annual cost, the derivation of certain formulas with which to calculate the value of the certain elements of annual cost, and data on the value of certain other elements of annual cost. Formulas are also derived for use in computing other factors relating to operation, such as capacity of the line, adjusting forecasts and proofs for changes in the traffic density, etc.

This chapter will be of greatest value only in so far as one is thoroughly familiar with its organization, arrangement, and content. This will be most readily accomplished by a study of the table of contents.

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CHAPTER III

Principles and Economics of Signaling

PRINCIPLES OF RAILROAD SIGNALING

The purpose of railroad signals is the transmitting of information to employees in charge of the operation of trains.

Safety was undoubtedly the original purpose for which signals were installed and the fundamental principles were centered around this original purpose, although in actual application it is impracticable to separate the principles pertaining to safety from those pertaining to facility of train movement, and since they are so interrelated they will be stated without regard to either safety of train movement or the facilitation thereof.

The principles are submitted as fundamentals of fixed signaling regardless of whether they be of the semaphore, color light, position light or color position light type. They do not refer to construction details, which details may properly be covered by specifications prepared, or in the course of preparation, by the Signal Section, Association of American Railroads.

Modern signaling is developed from three fundamental indications which were approved by the American Railway Association in 1910:

1. Stop
2. Caution
3. Proceed

These indications modified to meet present-day operating conditions are published by the Association of American Railroads in the current issue of the Standard Code.

The principles of railroad signaling as they relate to design, construction and installation of signal systems and to train operation are as follows:

Design and Construction

Reliability
Uniformity
Simplicity
Distinctiveness
Expansive capabilities

Reliability:

This requirement is given priority over all other factors so that safety and facility of train movement may be obtained.

Uniformity:

Uniformity in aspects and indications is necessary to avoid confusion. One name and indication should apply to those aspects indicating the same action to be taken and the same aspect should not be used with any other name and indication.

Simplicity:

Consistent with requirements, simplicity is an important factor in the design and construction of a signal system.

Distinctiveness:

A signal system should give definite information for the safe and expeditious movement of trains. Signals used should be distinctive in design so that the aspects can be unmistakably determined by the employees operating trains. The action required by the indication of a signal aspect should be definite, readily understandable, and permit of only one interpretation.

Expansive capabilities:

Light traffic and simplicity in track layout requires a less elaborate signal system than does heavy traffic and more complicated track layouts; however, the signaling for the light traffic or the simple track layout should, for economic reasons, be capable of expansion to provide for increasing traffic to the ultimate capacity of the railroad.

Installation

Location
Visibility
Spacing
Protection

Location:

Signals should, as far as practicable, be located:

1. To the right of and adjoining the track to which they refer.
2. Back of fouling point to protect converging and opposing train movements.

Visibility:

Signals should be so located as to give the best possible view to enginemen on approaching trains.

Spacing:

Each roadway signal shall be located with respect to the next signal or signals in advance which govern train movements in the same direction so that the indication of a signal displaying a restrictive aspect can be complied with by means of a brake application, other than an emergency application, initiated at such signal, either by stopping at the signal where a stop is required, or by a reduction in speed to the rate prescribed by the next signal in advance where reduced speed is required.

Protection:

The protection desired must be given careful consideration and the installation should be in accordance with the recommended practices of the Signal Section, A.A.R.

Systems of Signaling in Service

Basically, all signal systems now in service on the railroads are arranged to meet, as nearly as possible, the conditions set forth in the foregoing principles.

Chapter II—Symbols, Aspects and Indications explains in detail the aspects and indications displayed by the different types of signals, as well as the various systems in effect, and it is recommended that the student study Chapter II carefully in order to obtain complete information of all details regarding any particular system and type of signal.

METHOD OF FORECASTING AND PROVING THE ECONOMIC VALUE OF SIGNALING

General

The economics of signaling may be broadly resolved into either "forecasting" or "proving" the economic value of a proposition.

"Forecasting" refers to the determination of the results if a proposition were to be installed—a prospective calculation.

"Proving" refers to the determination of the results after a proposition has been installed—a retrospective calculation or check.

In either case, this means the preparation of an economic statement (A.A.R. Signal Section Form 24, page 91) in which is set forth the cost, the gross saving, the net saving, and the return on the investment.

In either case also, the procedures to be followed are similar, except that forecasting requires the setting up of an assumed operating method on the territory under consideration in order that the probable results may be evaluated by comparison either with the existing method or some other assumed method; whereas, proving is the evaluation of the results obtained with the actual method by comparison with the results that were obtained with the method prevailing prior to the change.

Occasion may arise to forecast the comparative results with two different methods. In such a case, the over-all comparison may usually be obtained by comparing each assumed method with the present method.

Since a discussion of the procedure applying to a forecast requires a consideration of more factors and the tentative solution of a greater number of problems, the following is based on that premise.

The several steps leading to the preparation of the economic statement are:

1. Set up an assumed operating method.

2. Determine the change in the elements of annual cost.

3. Determine the value of each element.

4. Determine the change in annual cost by multiplying the change (2) by the value (3).

5. Determine the cost of the installation.

6. Compute the annual return on the investment by dividing the change in annual cost (4) by the cost of the installation (5).

The physical organization of a railroad may be divided into three general classifications: (a) permanent way, (b) rolling stock, and (c) operating method.

Generally, the operating method is of primary concern. That is to say, given the permanent way and rolling stock, there remains as the variable the operating method for moving the rolling stock over the permanent way. Nevertheless, a thorough and well engineered study should, of course, consider permanent way modifications that would result in a better application of the operating method. Then, too, there are times when changes in the rolling stock (usually motive power) would be under contemplation in addition to the change in the operating method.

Every study presents its own problems—its own probable results; yet the same general method of procedure may usually be followed.

It is important that the capabilities, peculiarities, and disadvantages of both the existing operating method and the proposed operating method be well known and thoroughly understood, for upon this information is dependent a true, engineeringly sound comparison of the performance or results.

A description of each of the various operating methods from the above viewpoint is included in this chapter, beginning on page 97.

Conditions Before

The operating conditions existing before, which will serve as the basis of comparison of results, are known and the performance may be found in various records as follows:

1. The physical plant is recorded on various engineer and signal track plans, and valuation maps. It has been found that the working plan made for the study best serves its purpose when made to scale; therefore, those records should be used which provide the stationing required to lay out the scale working track plan. It has also been found that at least one trip over the road is necessary to check this plan. Incidentally, a trip increases one's familiarity with the territory, and this is conducive to better judgment throughout the study.

2. Basic train time data are recorded on the dispatcher's train sheets. Here again, one finds that, from the viewpoint of a forecast, the data are not complete, and the gaps must be filled in by investigating the following:

   (a) Conductor's wheel reports. These reports are helpful in locating train stops made for the purpose of setting out or picking up cars. without regard, of course, to the time consumed in doing the work. A reproduction of a typical wheel report is shown in Fig. 1,

   (b) Conductor's delay reports. While the dispatcher's train sheets frequently show remarks pertaining to the delays inflicted on certain trains, this information is usually incomplete. On some railroads, the conductors are required to fill in detail forms, and this information is most important because it is these delays that can frequently be eliminated by the proposed signal system. A reproduction of a typical delay report is shown in Fig. 2.

   (c) Conversations with operating officials. While this is not in the nature of recorded data, many conditions are brought to light which either would be rectified by the proposed signal system or should be considered in designing the system.

   (d) Observations at "critical" points where there is a considerable amount of delay due either to congestion or the performing of work.

The information relating to train movements is best consolidated, correlated, and put into shape for forecasting by preparing graphic train charts. The mechanical preparation of such charts is covered beginning on page 107.

The number of typical days of operation which should be studied is dependent upon the variation in operating conditions and practices, and the degree of

TYPICAL CONDUCTOR'S WHEEL REPORT

4-46-50M

REPORT OF__________________TRAIN NO.______________DATE______________________19_____

CONDUCTORS WILL ENTER MILEAGE OF EACH CAR SEPARATELY

	ROAD INITIAL	KIND	CAR NUMBER	L E	WHERE TAKEN	WHERE LEFT	DESTINATION	CONTENTS	MILES HAULED		TONNAGE			
											COMMERCIAL		COMPANY	
									LOADED	EMPTY	CAR	FREIGHT	CAR	FREIGHT
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														
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35														
36														
37														
38														
39														
40														
41														
42														
43														
	CABOOSE													

THIS SPACE FOR USE IN CAR ACCOUNTANT'S OFFICE

Fig. 1.
(Actual size 8⅛ by 12 inches)

TYPICAL CONDUCTOR'S DELAY REPORT
CLASSIFICATION OF TRAIN DELAYS

DIVISION__________ SUPT.__________ DATE__________ 19___

TRAIN NO.	ENGINE NO.	DIRECTION	FROM	DEPARTED	TO	ARRIVED	LOADS	EMPTIES	TOTAL TONS
				M		M			
				M		M			
				M		M			
				M		M			

DETAIL OF DELAYS IN MINUTES

STATION OR BETWEEN STATIONS	1					2	3	4		5				6	7	8	REMARKS
	Loading or Un-loading Freight	Hot Boxes	Defec-tive Air Brakes	Switch-ing Crippled Cars	Taking on or Leaving Cars	For Way-Bills	Waiting to Get into Yard	For Orders	Meeting or Passing Trains and Block Signals	Waiting for Engine	Taking Coal	Taking Water	Engine Failures	Doubling	Waiting for Pusher	Other Causes	

NAME OF EMPLOYEE	OCCUPATION	REPORTED FOR DUTY		WENT OFF DUTY		TOTAL TIME ON DUTY		TIME OFF DUTY PRIOR TO THIS TRIP	
		DATE	TIME	DATE	TIME	HOURS	MINS.	HOURS	MINS.

INSTRUCTIONS

1. Conductors will mail this report to Superintendent at the end of run.
2. Conductors of passenger trains in addition to this report will telegraph delays in detail at the end of each trip.
3. Delays should be explained in "Remarks" column as far as practicable. Delays shown under "Other Causes" should be explained in every instance.

Fig. 2.
(Actual size 7⅜ by 11 inches)

accuracy either required or desired. Obviously, better averages are obtained from a study of many days rather than a few. However, accuracy is dependent quite as much on the care exercised in choosing the typical days, and it may be necessary on occasion to proceed well into the study of a selected day before it can be determined that it is either typical or proportionately representative, and should be either included in or excluded from the forecast.

If it were possible to select a single day's operation which would represent typical and average conditions, the procedure would be simplified. However, this is difficult, if not impossible, as no considerable number of possible determining variables can be expected to occur in any one day. Moreover, if it could be assumed that delays caused by train interference are directly proportional to train density, then it would not be necessary to select days that represent average density, as an average could be derived from this proportion. However, this proportion cannot be relied upon for accurate results because of the variables incident to train operation. It is unusual for traffic to be evenly distributed over the 24-hour period, and congestion or traffic saturation usually takes place over relatively short periods of the day. An approximation may be obtained from a study of a well-chosen single day's operation, and the use of the before-mentioned proportion to derive the delay time for days having a different traffic density. In fact, when forecasting the results with a greater traffic density than has been before actually experienced on a division, it is necessary to make use of a proportion.

The selection of typical days may be facilitated by making a count from the train sheets of the trains per day over a period of a year and calculating the average, after which the required number of test days having the same average may be selected. The chief dispatcher may also be of assistance in determining whether a day is typical.

While it is somewhat easier to use successive days, it is sometimes desirable to select a peak traffic density day to demonstrate how the proposed system will handle the traffic, a light traffic density day to demonstrate that the proposed system will even here effect savings, and one, three, five or more days such that the test period will represent the average.

In some cases, it may be necessary to extend the test days into a year's operation by means of two or more proportion factors, each of which is the ratio of the number of days that operation would be typical to the number of days in a year.

Conditions After

In the case of forecasting, setting up the conditions that will exist after the proposition is installed is difficult, and yet this phase of the study is most important, for upon the decisions made at this time rests the ultimate quality of the project, how well it fits into the operating picture, the results that will be obtained, the cost of the installation, and the return on the investment. It is here that considerable judgment must be exercised, and logic and experience brought to one's assistance. The conditions after can be divided into three parts: known, required, and assumed.

Known.

Obviously, certain known conditions will remain the same after as before—grades, curves, bridges, highways, railroad crossings, stations, junctions, connections with other railroads, yards, etc.

Other known conditions that usually remain the same, but may be under consideration for change, are: motive power, train consists, number of trains, coal and water service facilities, train stops for setting out and picking up, etc.

Of course, it may be desirable to modernize the physical layout at one or more of these points, in order to eliminate unnecessary facilities, simplify the signaling, improve train operation, etc., at the same time as the major improvement is being made.

Required.

When the present conditions are being recorded on the graphic train charts, there will usually be brought to light certain operating conditions that dictate what signaling facilities should be provided. In this category will fall such items as:

(a) Capacity of the line.

It is obvious that the capacity must be adequate for the present and probable future traffic, measured in trains per day, that must be handled. The traffic must be considered in the light of its distribution or density, and the bunching of trains at some period of the day as a result of schedule requirements that cannot be changed must be used as the traffic upon which to base the capacity.

It is also obvious that the provision of excess capacity, while it might have some beneficial effect on the flexibility of operation and thus on the saving in time, would increase the cost of the signal installation and the cost of maintenance of the excess plant facilities.

The capacity of the line in trains per day and the time spacing of the sidings in minutes are related as follows:

$$\text{Potential capacity} = \frac{1440 \times 2}{\text{maximum gross headway}}$$

$$\text{Practical capacity} = \text{potential capacity} \times f$$

Where

1440 is the number of minutes in 24 hours

2 is a train in each direction

f is a factor to account for practical operating conditions

Maximum gross headway is the maximum of the net headways plus allowances for one train to enter and leave a siding

Net headway is the sum of the non-stop running times for both directions between adjacent sidings

This analysis may be performed either by preparing a table or by making a time distance chart.

(b) Time spacing of sidings.

The operating sidings to provide the above capacity should be located on the basis of a uniform time spacing.

Time spacing is the proper unit of measurement because it takes into consideration all the factors that influence the operation of trains, such as: distance, speed, grades, time for entering and leaving the sidings, time for taking fuel and water, etc.

(c) Sidings that should be power-operated.

In studying the time spacing of the sidings as above, it becomes apparent that a compromise must be made because it must be taken into consideration that the railroad is already built and only more or less slight modifications would be economically justified.

This then resolves itself into taking those sidings which are most nearly equally time spaced as the sidings to be power-operated for through train operation.

(d) Sidings that should be eliminated.

In order to reduce the cost of the signal installation and also the cost of maintenance, those sidings that are not power-operated should be eliminated.

These sidings should be physically removed, because, in addition to the direct costs above, it has been found that many times a train dispatcher will lapse into thinking in terms of the previous operation and try to use these hand-operated sidings, with the result that time is lost rather than saved.

A committee of the American Association of Railroad Superintendents at their Annual Meeting in 1948 stated:

> "If we take into consideration the improved performance by the use of power-operated switches instead of hand-throw switches, we will find the distance between sidings can be increased four to five miles and a freight train can leave one siding and enter the next siding 10 miles away with power switches in less time than the moves could be made with switches handled by trainmen with sidings spaced 5 miles apart. The elimination of 50 per cent of the sidings would keep the cost of centralized traffic control more in line with the cost of automatic block signals and we would still retain all advantages of operation of C.T.C. over operation under time-table and train orders."

(e) Sidings that could be eliminated for through train operation but should be retained either in whole or in part for work purposes.

In order to eliminate interference to through trains by local or way freight trains which regularly do considerable work at certain locations, it may be found desirable to retain either part or all of certain sidings and equip them with only the minimum of signal devices.

(f) Siding extensions to handle the length of train being operated.

In order that those sidings which are power-operated for through train operation will be fully utilized and not place restrictions on the proper arranging of meets and passes on a minimum time loss basis, the sidings should have a minimum car capacity adequate to handle the longest present and probable future train.

It is, of course, obvious that the minimum length of siding need only be adequate for the longest train in the direction having the shorter trains.

Such siding extensions should be made before the signal system is installed in order to avoid the cost of moving the signal equipment, which usually involves, not only the signal equipment at the siding end, but also the approach signals, certain of the intermediate automatic signals, the track circuits, and under certain conditions a change in signal aspects. Conversely, when the siding is extended before the signal installation is made, it may eliminate a block shorter than braking distance with its attendant complication in signal aspects.

(g) Signaling at "standard or typical" locations.

(h) Signaling at "special" locations.

(i) Track and signal layouts at locations where special work must be performed.

(j) The proper location of fuel and water facilities.

(k) Such facilities as are specified by railroad officials.

(l) The provision of additional aspects in approach of short blocks to regulate the speed and thus provide the equivalent of adequate braking distance.

Assumed.

Certain conditions cannot be determined with exactitude, but rather, must be evolved as the study progresses. In other words, certain assumptions must be made and the operation therewith worked out on the graphic train charts to see whether it is satisfactory; if not, the assumptions must be modified and again tested, continuing until a satisfactory solution is obtained.

Some of the items are:

(a) The choice between two-indication station-to-station signaling or three-indication block signaling.

(b) The number and location of intermediate signals required to permit following movements to take place on the desired headway.

(c) Additional aspects that should be provided on the approach signal to inform the engineman that the diverging route is aligned and the signal governing over it is cleared.

(d) The method of control of outlying switch locks for the specific traffic conditions.

(e) The adequacy and location of the controlled operating sidings.

Determination of Change in Magnitude, and Value, of the Elements Involved in the Annual Cost

There are many elements of annual cost; however, since every study is peculiar to itself, some of these elements may not change. Therefore, it is well to make an estimate of those elements which it is expected will be involved. Either the table of contents or the following discussions may be used as a check list, the object being to insure that none is overlooked.

Once the change in the magnitude of the various elements of annual cost has been determined, it becomes necessary to place a unit value on each in order to determine the annual saving in dollars.

Some of the unit values are obtained from the records of the railroad and will be quite accurate, others may be computed from formulas derived by the Signal Section, and still others will have to be estimated on the basis of existing similar installations.

PAYROLL

Change

The change in payroll is tangible and rather easily computed. The two classes of employees involved are operating (road) employees and non-operating employees.

OPERATING (ROAD) EMPLOYEES

Because of the method of compensating operating employees, and unless a run can be eliminated, the saving in payroll is that due to a reduction in the overtime only.

Since the improvement in operation generally affects the passenger trains only incidentally and slightly, the following explanation is confined to freight train employees; however, should the improvement in operation affect materially the passenger train employees, the change should be considered on a similar, though different, unit basis.

Road pay.

Road employees are paid as follows:

When the run is 100 or less miles, the basic daily rate.

When the run is 100 or more miles, 1/100th of the basic daily rate for each of the miles.

When the run is 100 or less miles, overtime starts after 8 hours.

When the run is 100 or more miles, overtime starts after the number of hours obtained by dividing the miles by 12½ miles per hour.

There is a basic daily rate for enginemen, firemen, and helpers; each of which is based on the weight on drivers of locomotive and class of service (through freight, and local and way freight).

There is a basic daily rate for conductors, flagmen, and brakemen; each of which is based on the service (through freight, and local and way freight), and the territory (Eastern & Southeastern and Western).

The overtime rate per hour is 1½ times the rate per hour which is obtained by dividing the basic daily rate by 8. Overtime is prorated on a minute basis.

The rates applicable to the territory being studied may be obtained from either the dispatcher or the time clerk.

It is common practice for the time clerk to have these rates computed on an hourly basis.

The "before" time on duty for each trip is found either on the dispatcher's train sheet or on the time clerk's report or on the trainmen's time report.

The overtime for the trip is, of course, the difference between the time on duty and the time after which overtime starts.

Either the "after" time on duty or the saving in time for the same trip is determined from the graphic train chart redispatching.

Thus, in those cases where a trip was made with overtime and the graphic train chart shows a saving in time, there would be that saving in overtime, but not to exceed the original overtime.

Terminal delay pay.

Initial terminal delay is paid on a minute basis to enginemen, firemen on steam power, and helpers on other than steam power in through freight service after 75 minutes unpaid terminal time has elapsed from the time of reporting for duty until the time the train actually starts on its road trip from the yard track where the train is first made up. Where mileage is allowed between the point of reporting for duty and the point of departure from the track on which the train is first made up, each mile so allowed will extend by 4.8 minutes the period of 75 minutes after which initial terminal delay payment begins. When road overtime accrues during any trip or tour of duty, in no case will payment for both initial terminal delay and overtime be paid, but whichever is the greater will be paid. When a tour of duty is composed of a series of trips, initial terminal delay will be computed on only the first trip of the tour of duty.

Final terminal delay is paid on a minute basis to enginemen, firemen on steam power, and helpers on other than steam power in through freight service after 30 minutes unpaid terminal time has elapsed from the time the engine reaches the switch, or signal governing over same, used in entering the final terminal yard track where the train is to be left, or yarded, or standing behind another train waiting at such switch or signal until finally relieved from duty. Where mileage is allowed between the point where final terminal delay time begins and the point where finally relieved, each mile so allowed will extend by 4.8 minutes the period of 30 minutes after which final terminal delay payment begins. After road overtime commences, final terminal delay does not apply and road overtime is paid until finally relieved from duty. In local freight service, time consumed in switching at final terminal is not included in the computation of final terminal delay time. When a tour of duty is composed of a series of trips, final terminal delay is computed on only the last trip of the tour of duty.

Final terminal delay is paid on a minute basis to conductors and trainmen in freight service after 30 minutes unpaid terminal time has elapsed from the time the train reaches the designated main track switch connection with the yard track, or signal governing same, or standing behind another train waiting at such switch or signal until finally relieved from duty. In local freight service, time consumed in switching at final terminal is not included in the computation of final terminal delay time. If an arbitrary allowance is made at the final terminal under some rule, practice or interpretation, there is no duplication of payments, but whichever is greater is paid.

In some cases where there are no switch tenders or power switches, the head brakeman is called for earlier duty to handle the switches for the engine in and out of the road house leads.

In many cases, engine crews are on duty from 5 to 30 to 45 minutes longer than the train crews.

The original terminal delay can be computed from the data on the dispatcher's train sheet, and the after terminal delay time can be obtained from the graphic train chart, the difference being the saving that can be made if the original terminal time resulted in terminal delay pay.

Information on the terminal overtime agreement in effect for the specific case under study can be obtained from the time clerk.

While operating employees receive vacations, it is rather difficult to make this adjustment, and it is the usual practice to omit this refinement.

NON-OPERATING EMPLOYEES

The employees involved may be dispatchers, train directors, operators, agent-operators, levermen, telegraphers, signal department employees, engine terminal employees, etc.

The change in personnel is determined by analyzing the requirements before and after in the light of the type of system and the work it will do. For example, with centralized traffic control there is no need for intermediate operators.

It should be remembered that sometimes agent service is maintained at a location only because an agent-operator can handle all the duties, and after the operator duties are eliminated, the remaining agent duties are not sufficient to justify the retention of a full time agent. For example, it is frequently possible to combine the necessary duties at two, or more, stations under one agent.

Since non-operating employees work 5 days per week, those jobs which have either 6 or 7 days per week coverage will require a relief, who will also work only 5 days per week.

Non-operating employees, except clerks and telegraphers, receive a vacation of 1 week (5 days) after 1 year of service, and 2 weeks (10 days) after 5 years; while clerks and telegraphers receive a vacation of 1 week (5 days) after 1 year, 1½ weeks (7½ days) after 2 years, and 2 weeks (10 days) after 3 years.

On jobs which have either 6 or 7 days per week coverage, this means that a vacation relief must be provided, and the relief too, when on full time, receives a vacation.

This means that a 5-day per week job amounts to 254 days covered (excluding 7 holidays), plus 10 vacation days, which equals 264 days at 8 hours per trick, or 2,112 hours per trick per year.

This means that a 6-day per week job amounts to 306 days covered (excluding 7 holidays), plus 10 vacation days, plus 2 days of the relief's vacation, which equals 318 days at 8 hours per trick, or 2,544 hours per trick per year.

This means that a 7-day per week job amounts to 365 days covered, plus 3½ (i.e., 7 x ½) holiday overtime days, plus 10 vacation days, plus 4 days of the relief's vacation, which equals 382½ days at 8 hours per trick, or 3,060 hours per trick per year.

Of course, where there is a scarcity of employees and a regular employee works either a relief or vacation trick, that employee would receive his overtime rate for that trick.

On some railroads, a flat 3 per cent is added to cover the vacation expense.

After the payroll change is computed, an adjustment should be made to cover the additional items of 6.25 per cent for railroad retirement taxes on the first $300 of monthly compensation, 0.5 per cent for unemployment insurance on the first $300 of monthly compensation, any other personal insurance contributions payable by the railroad, and any state payroll taxes payable by the railroad.

There are two methods of handling wages and salaries:

(a) Include in the gross saving the wages and salaries of all employees required with the "before" method of operation, and include in the annual operating expense the wages and salaries of all employees required with the "after" method of operation.

This has the advantage of giving a complete statement of what is required both before and after the improvement is made.

It has the disadvantage of more or less duplication, and making a lengthy economic statement.

(b) Include in the gross saving only the wages and salaries of the employees eliminated.

This is the method usually employed because it simplifies the economic statement, the tabulation made to determine the saving providing the information as to the requirements before and after.

Value

The value of the payroll saving for the two classes of employees involved is as follows:

OPERATING (ROAD) EMPLOYEES

Road pay.

In practically all cases, the payroll saving for road employees is that which results from a saving in overtime; therefore, the overtime rate only is of interest.

Generally, the time clerk has computed the overtime rate per hour for each of the various employees in the various classes of service, and, in the case of the engine crews, for the several weight classifications of locomotives in use in that territory.

It thus becomes a simple matter to add the overtime hourly rates for

Engineman
Fireman
Conductor
Brakemen (number used on specific run)

to obtain the total overtime hourly rate for the crew.

Should the time saving for the engine crew and train crew differ, because of differing hours on duty, the overtime hourly rate for each should be computed.

Should the standard basic daily rates only be available, add the rates for

Engineman
Fireman
Conductor
Brakemen (number used on specific run)

to obtain the crew daily rate, which should be divided by 8 to obtain the crew straight time hourly rate, which should be multiplied by 1½ to obtain the crew overtime hourly rate.

For example (locomotive 300,000 and less than 350,000 pounds on drivers—through freight):

Class of employee	Number of employees	Standard basic daily rate	Total
Engineman	1	$15.99	$15.99
Fireman	1	14.15	14.15
Conductor	1	14.18	14.18
Brakemen	2	12.76	25.52
Crew basic daily rate			$69.84
Crew straight time hourly rate			$ 8.73
Crew overtime hourly rate			$13.10

Terminal delay pay.

Initial and final delay is paid for at straight time rates (Pro Rata)—information for the specific case under study may be obtained from either the time clerk or the yard master.

NON-OPERATING EMPLOYEES

The payroll saving for non-operating employees is that which results because of the elimination of positions, and thus is at straight time rates.

The rates applicable to the various classes of employees at the various locations may be obtained from the time clerk.

The computation of the reduction in non-operating payroll may be facilitated by the preparation of a tabulation similar to the following:

		Number of employees				
Station	Class of employee	Present	Proposed	Eliminated	Rate	Annual saving*

*7-day per week job computed on the basis of 365 + 3½ + 10 + 4 days @ 8 hours = 3,060 hours per trick per year.

6-day per week job computed on the basis of 306 + 10 + 2 days @ 8 hours = 2,544 hours per trick per year.

5-day per week job computed on the basis of 254 + 10 days @ 8 hours = 2,112 hours per trick per year.

TRAIN TIME

Change

The forecast of the change in time, with a given train density, under a proposed signal improvement may be less tangible than are the payrolls, but may be approximated with a satisfactory degree of accuracy.

This information is obtained from the graphic train charts, by redispatching the trains to show the anticipated operation under the proposed method.

The following factors enter into the redispatching of a train:

1. The non-stop running time, which is the running time the train would consume over the road if it did not encounter interference.

   This non-stop running time for the various sections of the road is determined either by a study of the actual running times of other similar trains or from discussions with the dispatchers or the running time of a test train.

2. Delays which actually took place and which were not due to train interference and could be expected to take place under the assumed conditions the same as before. These delays are those occasioned by switching, taking on supplies, breakdowns, etc. It should be remembered, however, that the proposed method may speed up the work and thus reduce the delay.

3. The starting time of trains from a terminal. Certain operating methods require more or less advance planning and preparation before a

train may leave the terminal and get under way on the road. In other words, when the dispatcher is informed that a train is ready to go, the amount of time required to prepare orders, etc., and the location of another train, may be such that the train must wait for the other train. Whereas, another operating method may be so flexible that the only consideration is the running times of the trains, and this would permit the immediate release of the train from the terminal.

The existence of this condition is difficult to determine, there is little in the records—sometimes in terminal delay reports; however, the yardmaster probably can be of assistance.

In this connection also, it has been found that a short time spacing to the first siding tends to increase the time saving possibilities.

TRAIN HOUR

It is obvious that the method of redispatching individual trains results in a tabulation of individual changes which may be totaled, averaged, and extended into an annual saving in train hours for which monetary values are available for each railroad or may be computed from available statistics for certain portions of a railroad embracing the territory under study.

TON MILES PER TRAIN HOUR

It is, of course, possible to compute from this basic information anticipated ton miles per train hour which may be compared with the present ton miles per train hour.

On some railroads, the symbol trains are scheduled from terminal to terminal and loaded so as to maintain that schedule; that is, if the train is behind schedule at a subterminal, the tonnage is reduced to enable it to pick up time while traveling to the next subterminal; and conversely, if it is ahead of schedule at a subterminal, the tonnage is increased. Therefore, where the operating method results in the elimination of train interference and a probable saving in time, the saving in time must be translated and the comparison made on the basis of ton miles per train hour.

TRAIN MILE

Where a signal installation improves the train performance so that increased tonnage may be handled and reduction can be made in the number of train miles required to move a given traffic, the train mile saving may be computed.

TRAIN SPEED

It is also possible to compute the anticipated average train speed in miles per hour which may be compared with the present average train speed.

Value (Cost)

TRAIN HOUR

For a number of years, the Signal Section has been trying to develop a cost for a "saved train hour" for use in evaluating the train hours saved through the installation of a signaling system.

It is obvious that the saving that can be made in the cost of the train hours as a result of a reduction in the number of train hours is not in direct proportion, because there are certain expenses chargeable to the production of the train hours that are independent of the number of train hours produced.

To date, the endeavor to find a cost for a "saved train hour" has not been fully realized, but the work has resulted in a method whereby it is possible to compute the statistical or average cost of each train hour produced on the railroad, or, to some extent, on a selected portion of the railroad depending upon the territory breakdown used in apportioning charges to the various account classifications.

The investigation involved both the decision as to what items enter into the cost and where to find the dollar figures for the items.

In the beginning, the following items were included:

1. Wages, train and enginemen (overtime only)
2. Train fuel
3. Water for train locomotives
4. Lubricants for train locomotives
5. Other supplies for train locomotives
6. Enginehouse expenses—train
7. Train supplies and expenses
8. Locomotive repairs
9. Locomotive depreciation
10. Locomotive retirements
11. Interest on locomotive investment
12. Payroll taxes

Further consideration and investigation from time to time resulted in the elimination of the following items:

1. Wages, train and enginemen (overtime only).

   Originally, this item was considered proper in view of the fact that it was desired to provide an all-inclusive statistical train hour cost with which to evaluate, by means of one element, the saving producible by a signal system.

   Since there was no I.C.C. account classification to cover the overtime for road freight train service employees, it was necessary to estimate this portion of the cost by applying a factor to selected items appearing in the Form A report.

   For some time it has been evident that the determination of the saving in overtime wages can be easily and accurately computed from data obtained from the graphic train charts for the specific train operation and signal installation; therefore, this item was first entered separately in, and later omitted from, the tabulation by railroads.

   Accordingly, where overtime, train stops, etc., are computed separately and where the train hour cost is used only to evaluate the saving in train hours as a result of a reduction in time on the road, the following items should be included:

Items	I.C.C. acct. classification	Form A Report (Note) Page	Sched.	Line	Column
2. Train fuel	394	309	320	132	e
Train power produced	395	309	320	133	e
Train power purchased	396	309	320	134	e
3. Water for train locomotives	397	309	320	135	e
4. Lubricants for train locomotives	398	309	320	136	e
5. Other supplies for train locomotives	399	309	320	137	e
6. Enginehouse expenses—train	400	309	320	138	e
7. Train supplies and expenses	402	309	320	140	e
8. Steam locomotives—repairs—other	308	307	320	76	e
Other locomotives—repairs—other	311	307	320	78	e
9. Steam locomotives—depreciation—other	331–51	314	330	432	e
Other locomotives—depreciation—other	331–52	314	330	434	e
12. Payroll taxes (on labor of Items 6 and 8)					
Freight train hours		508	531	29	b

Note.—Page, schedule, line, and column references refer to I.C.C. Annual Report Form A for the calendar year 1952, and may change in subsequent years.

The I.C.C. account classification is that from which the charges should be obtained when computing the train hour cost for a specific portion of a specific railroad.

The Form A report reference is that from which the charges should be obtained when computing the train hour cost for the railroad for the last reported period.

The figures from the above accounts are used as follows:

2. Train fuel.
   I.C.C. Account 394 does not include the cost of on-line fuel transportation. An allowance should be made over the listed cost of train fuel to cover the cost of its on-line transportation. For the year 1946, this cost averaged 5.31 mills per net ton mile for Class I railroads in the United States. Each railroad can provide its own cost per ton mile. Also, each railroad has a record of its average length of haul.

3. Water for train locomotives.
   Use without adjustment.

4. Lubricants for train locomotives.
   Use without adjustment.

5. Other supplies for train locomotives.
   Use without adjustment.

6. Enginehouse expenses—train.
   Use without adjustment.

7. Train supplies and expenses.
   Use without adjustment.

8. Locomotive repairs.
Use without adjustment.

9. Locomotive depreciation.
This item should include charges for all road freight locomotives. Reports to the I.C.C. covering these charges are classified as Account 331, Sub-accounts 51 and 52.

Prior to 1949, Annual Report Form A did not provide for separation of charges to these accounts between yard and road freight locomotives, necessitating approximate apportionment on the basis of the ratio of road freight locomotive repairs to total freight locomotive repairs. Beginning with the year 1949, Annual Report Form A provides for separation of Sub-accounts 51 and 52 between yard and road freight locomotives thus permitting direct assignment of depreciation charges for road freight locomotives.

12. Payroll taxes.
This item should include payroll taxes on the labor portions of Item 6, enginehouse expense, and Item 8, locomotive repairs.

The amount in Item 6, enginehouse expense, obtained from I.C.C. Account 400 includes both labor and materials; thus, where possible, the labor portion of this amount should be obtained from the detail accounts; otherwise, it may be assumed that 85 per cent of this amount represents the labor charges upon which the tax rate applies.

The amount in Item 8, locomotive repairs, obtained from I.C.C. Accounts 308 and 311 also includes both labor and materials; thus, where possible, the labor portion of this amount should be obtained from the detail accounts; otherwise, it may be assumed that 70 per cent of this amount represents the labor charges upon which the tax rate applies.

The 85 per cent and 70 per cent factors were obtained as a result of the analysis of detail accounts.

The rate for payroll taxes is regulated by Federal law and prescribed to change from time to time, in which event it will, of course, be necessary to change the rate accordingly. As of January 1, 1952, the rate is 6.25 per cent for railroad retirement on all compensation up to $300 per month and 0.5 per cent for Unemployment Insurance on all compensation up to $300 per month; therefore, in order to compensate for the fact that a part of the labor in the two items is paid at a rate in excess of $300 per month and thus not subject to taxation, a payroll tax rate of 5.5 per cent is considered adequate.

The average cost of a train hour may be computed as follows:

$$\text{Train hour cost} = \frac{\text{sum of Items 2 through 9 and 12}}{\text{road freight train hours}}$$

It is apparent that the cost so derived will represent the average for the conditions existing on the territory covered by the charges to the accounts for the corresponding territory. Should the conditions for the specific territory under investigation be out of line with the conditions for the remainder of the territory, due consideration should be given to compensate for the unusual conditions.

A case of this kind would be where grade conditions are severe and a relatively high percentage of the trains are operated with double-headed power, pushers, or helpers.

The train hour cost, on the above basis, has been computed for each of 78 railroads from reports submitted to the I.C.C. by the railroads in the Annual Form A reports, and this information is shown in Table I.

In general, the train hour cost (which represents the direct outlay such as of money, time, and labor) is in proportion to the value of a saved train hour; because the value of a saved train hour is the cost (probably somewhat less than the above cost) plus the value (i.e., worth) of one or more of the intangible items as follows:

- Availability of equipment
- Improved service to shippers
- Competitive position with other carriers
- Value of on-time deliveries, thereby saving penalty of missed market deliveries
- Character and volume of traffic
- Local operating condition of railroad subdivision as compared to the system

Example:

Freight train hours (Schedule 531) 2,183,501

Fuel, supplies, enginehouse expense and locomotive repairs:

Item	Account	Freight proportion (Sched. 320)	Cost per freight train hour
2	394 Train fuel	$23,500,543	$10.76
	395 Train power produced	163,086	0.07
	396 Train power purchased	3,624,593	1.66
3	397 Water for train locomotives	1,365,213	0.63
4	398 Lubricants for train locomotives	1,087,016	0.50
5	399 Other supplies for train locomotives	545,961	0.25
6	400 Enginehouse expenses—train	9,469,421	4.34
7	402 Train supplies and expenses	15,827,889	7.25
8	308 Steam locomotives—repairs—other	13,520,428	6.19
	311 Other locomotives—repairs—other	20,187,059	9.25
	Total—Items 2 to 8	$89,291,209	$40.90

Road freight locomotive depreciation:

Item	Account	Freight proportion (Sched. 330)	Cost per freight train hour
9	331–51 Steam locomotives—depreciation—other	$2,047,950	xxx
	331–52 Other locomotives—depreciation—other	6,390,620	xxx
	Total	$8,438,570	$3.86

Payroll taxes on labor applicable to road freight locomotive repairs and enginehouse expenses:

Item	Account	Freight proportion	Cost per freight train hour
	Labor included in enginehouse expenses, 85% of Item 6 above	$8,049,008	xxx
	Labor included in locomotive repairs, 70% of Item 8 above	23,595,241	xxx
	Total labor	$31,644,249	xxx
12	Payroll taxes (labor × 5.5%)	$1,740,434	$ 0.80
	Total train hour cost (excluding train crew wages)		$45.56

TRAIN MILE

Where there is a saving in the train miles, the unit cost should be that for a "saved train mile," because it is obvious that a reduction in the number of train miles does not result in a direct reduction in the cost of the train miles since there are certain expenses chargeable to the production of the train miles that are independent of the number of train miles produced.

As a measure of the cost of a "saved train mile," the following specified elements entering into the cost of the ordinary freight train mile

Road freight train crews' wages
Fuel, supplies, enginehouse expense, and locomotive repairs
Payroll taxes on crew wages and labor applicable to locomotive repairs and shop and enginehouse expense

for each railroad were obtained from reports submitted by railroads to the I.C.C. (Form A), and this information is shown in Table II.

Where possible, this cost should be computed for the operating territory under study.

TABLE I

Specified Elements of Train Hour Cost per Road Freight Train Hour—Year 1952 (Excluding road freight train crews' wages)

Railroad	Elements of train hour cost (per road freight train hour): Fuel, supplies, enginehouse expense and locomotive repairs	Road freight locomotive depreciation	Payroll taxes on labor applicable to road freight locomotive repairs and enginehouse expense a	Total train hour cost (excluding train crew wages)
1	2	3	4	5=2+3+4
Item number in report	Items 2 to 8	Item 9	Item 11	Items 2 to 11
NEW ENGLAND REGION:				
1 Bangor & Aroostook	$22.04	$5.89	$0.36	$28.29
2 Boston & Maine	28.95	2.07	0.63	31.65
3 Central Vermont	31.56	0.53	0.54	32.63
4 Maine Central	19.50	2.70	0.42	22.62
5 New York, New Haven & Hartford	32.76	3.06	0.64	36.46
6 Rutland	15.89	1.13	0.34	17.36
GREAT LAKES REGION:				
7 Ann Arbor	17.87	4.91	0.27	23.05
8 Delaware & Hudson	50.63	4.25	1.09	55.97
9 Delaware, Lackawanna & Western	27.35	4.12	0.43	31.90
10 Erie (Incl. Chgo. & Erie)	30.30	4.53	0.53	35.36
11 Grand Trunk Western	35.99	0.76	0.54	37.29
12 Lehigh & New England	14.37	7.39	0.19	21.95
13 Lehigh Valley	35.41	6.00	0.58	41.99
14 Monongahela	27.78	1.20	0.52	29.50
15 New York Central	34.21	3.02	0.60	37.83
16 New York, Chgo. & St. Louis (Incl. W. & L. E.)	39.89	1.11	0.72	41.72
17 New York, Ontario & Western	17.97	4.11	0.40	22.48
18 Pittsburgh & Lake Erie	60.65	2.19	1.02	63.86
19 Wabash	29.83	4.87	0.39	35.09
CENTRAL EASTERN REGION:				
20 Baltimore & Ohio	37.01	1.83	0.76	39.60
21 Bessemer & Lake Erie	67.67	7.35	1.37	76.39
22 Cent. R.R. of New Jersey (Incl. C.R.R. of Pa.)	32.22	3.83	0.64	36.69
23 Chicago & Eastern Illinois	24.60	3.73	0.41	28.74
24 Chicago, Indianapolis & Louisville	29.11	4.14	0.55	33.80
25 Detroit, Toledo & Ironton	27.99	2.14	0.46	30.59
26 Elgin, Joliet & Eastern	17.60	2.40	0.37	20.37
27 Illinois Terminal Co.	13.18	1.11	0.24	14.53
28 Long Island	21.16	1.37	0.47	23.00
29 Pennsylvania	40.90	3.86	0.80	45.56
30 Reading	30.24	3.34	0.54	34.12
31 Western Maryland	50.13	3.22	1.12	54.47
POCAHONTAS REGION:				
32 Chesapeake & Ohio (Incl. Pere M.)	39.98	5.17	0.76	45.91
33 Norfolk & Western	53.64	1.99	1.01	56.64
34 Richmond, Fred'burg & Potomac	40.40	4.52	0.57	45.49
35 Virginian	38.93	3.25	0.86	43.04
SOUTHERN REGION:				
36 Alabama Great Southern	38.43	8.89	0.87	48.19
37 Atlantic Coast Line	21.17	3.58	0.36	25.11
38 Central of Georgia	25.55	2.37	0.47	28.39
39 Cincinnati, New Orleans & Tex. Pac.	46.44	10.15	1.04	57.63
40 Clinchfield	41.64	5.62	0.81	48.07

a Payroll taxes calculated at rate of 5.50 per cent. Reduction from actual rate of 6.75 per cent account compensation in excess of $300 per month.

TABLE I—Continued

Railroad	Elements of train hour cost (per road freight train hour) Fuel, supplies, enginehouse expense and locomotive repairs	Road freight locomotive depreciation	Payroll taxes on labor applicable to road freight locomotive repairs and enginehouse expense a	Total train hour cost (excluding train crew wages)
1	2	3	4	5=2+3+4
Item number in report	Items 2 to 8	Item 9	Item 11	Items 2 to 11
SOUTHERN REGION—Continued:				
41 Florida East Coast	$26.89	$3.23	$0.42	$30.54
42 Gulf, Mobile & Ohio	36.79	4.93	0.77	42.49
43 Illinois Central	28.90	0.89	0.54	30.33
44 Louisville & Nashville	31.05	2.18	0.58	33.81
45 Nashville, Chattanooga & St. Louis	18.37	3.95	0.25	22.57
46 Norfolk Southern	18.58	1.57	0.44	20.59
47 Seaboard Air Line	30.45	6.90	0.56	37.91
48 Southern	28.85	5.11	0.61	34.57
NORTHWESTERN REGION:				
49 Chicago & North Western	26.40	3.47	0.43	30.30
50 Chicago Great Western	24.26	6.68	0.28	31.22
51 Chicago, Milwaukee, St. Paul & Pac	31.71	2.52	0.53	34.76
52 Chicago, St. Paul, Mpls. & Omaha	24.97	1.60	0.34	26.91
53 Duluth, Missabe & Iron Range	68.76	0.83	1.38	70.97
54 Great Northern	29.96	2.13	0.57	32.66
55 Minneapolis & St. Louis	19.94	2.91	0.43	23.28
56 Mpls.,St.Paul&SaultSte.Marie(Incl.Wis.C.)	28.80	2.72	0.52	32.04
57 Northern Pacific	38.12	1.20	0.71	40.03
58 Spokane, Portland & Seattle	19.65	3.16	0.33	23.14
CENTRAL WESTERN REGION:				
59 Atchison, Topeka & Santa Fe Sys	32.91	2.52	0.59	36.02
60 Chicago, Burlington & Quincy	27.19	2.64	0.38	30.21
61 Chicago, Rock Island & Pacific	23.31	1.81	0.38	25.50
62 Colorado & Southern	29.63	1.90	0.45	31.98
63 Denver & Rio Grande Western	44.62	3.98	0.87	49.47
64 Fort Worth & Denver	27.69	1.48	0.47	29.64
65 Northwestern Pacific	14.19	0.05	0.25	14.49
66 Southern Pacific	42.39	3.45	0.88	46.72
67 Union Pacific	54.22	2.51	0.97	57.70
68 Western Pacific	35.60	3.25	0.59	39.44
SOUTHWESTERN REGION:				
69 Gulf Coast Lines	23.30	0.82	0.47	24.59
70 International-Great Northern	27.57	3.64	0.57	31.78
71 Kansas City Southern	33.88	3.97	0.54	38.39
72 Louisiana & Arkansas	21.37	3.41	0.33	25.11
73 Missouri-Kansas-Texas	25.83	2.53	0.47	28.83
74 Missouri Pacific	31.79	3.46	0.58	35.83
75 Frisco Lines	27.22	4.07	0.46	31.75
76 St. Louis Southwestern	24.55	2.82	0.39	27.76
77 Texas & New Orleans	32.56	0.55	0.63	33.74
78 Texas & Pacific	28.67	6.79	0.41	35.87
Composite Average	34.33	3.05	0.64	38.02
AVERAGES BY REGIONS:				
New England	28.15	2.63	0.56	31.34
Great Lakes	34.51	3.20	0.60	38.31
Central Eastern	37.47	3.13	0.74	41.34
Pocahontas	44.21	3.98	0.84	49.03
Southern	28.81	3.52	0.55	32.88
Northwestern	30.86	2.47	0.55	33.88
Central Western	38.22	2.70	0.70	41.62
Southwestern	29.16	3.06	0.52	32.74

a Payroll taxes calculated at rate of 5.50 per cent. Reduction from actual rate of 6.75 per cent account compensation in excess of $300 per month.

TABLE II

Road Freight Train Crews' Wages and Specified Elements of Freight Service Cost per Ordinary Train Mile—Calendar Year 1952

Railroad	Road freight train crews' wages a	Fuel, supplies, enginehouse expense and locomotive repairs b	Payroll taxes on crew wages and labor applicable to locomotive repairs and shop and enginehouse expense c	Total
NEW ENGLAND REGION:				
1 Bangor & Aroostook	$1.40	$1.44	$0.10	$2.94
2 Boston & Maine	1.21	1.75	0.10	3.06
3 Central Vermont	1.20	2.22	0.10	3.52
4 Maine Central	1.08	1.35	0.09	2.52
5 New York, New Haven & Hartford	1.25	2.16	0.11	3.52
6 Rutland	0.76	0.87	0.06	1.69
GREAT LAKES REGION:				
7 Ann Arbor	0.89	0.99	0.06	1.94
8 Delaware & Hudson	1.17	2.65	0.12	3.94
9 Delaware, Lackawanna & Western	1.28	1.68	0.10	3.06
10 Erie (Incl. Chgo. & Erie)	1.24	1.72	0.10	3.06
11 Grand Trunk Western	0.98	1.78	0.08	2.84
12 Lehigh & New England	1.78	1.42	0.12	3.32
13 Lehigh Valley	1.39	1.80	0.11	3.30
14 Monongahela	1.62	2.77	0.14	4.53
15 New York Central	1.22	2.05	0.10	3.37
16 New York, Chgo. & St. Louis (Incl. W. & L. E.)	1.16	2.26	0.10	3.52
17 New York, Ontario & Western	0.95	1.17	0.08	2.20
18 Pittsburgh & Lake Erie	1.40	4.14	0.15	5.69
19 Wabash	0.95	1.36	0.07	2.38
CENTRAL EASTERN REGION:				
20 Baltimore & Ohio	1.34	2.59	0.13	4.06
21 Bessemer & Lake Erie	1.33	4.36	0.16	5.85
22 Cent. R.R. of New Jersey (Incl. C.R.R. of Pa.)	1.95	2.55	0.16	4.66
23 Chicago & Eastern Illinois	1.00	1.50	0.08	2.58
24 Chicago, Indianapolis & Louisville	1.00	1.70	0.09	2.79
25 Detroit, Toledo & Ironton	1.10	1.97	0.09	3.16
26 Elgin, Joliet & Eastern	2.53	2.61	0.19	5.33
27 Illinois Terminal Co.	1.03	0.98	0.07	2.08
28 Long Island	2.95	2.77	0.22	5.94
29 Pennsylvania	1.55	2.57	0.14	4.26
30 Reading	1.49	2.31	0.12	3.92
31 Western Maryland	1.26	3.51	0.15	4.92
POCAHONTAS REGION:				
32 Chesapeake & Ohio (Incl. Pere M.)	1.11	2.29	0.10	3.50
33 Norfolk & Western	1.13	3.26	0.12	4.51
34 Richmond, Fred'burg & Potomac	0.95	1.76	0.08	2.79
35 Virginian	1.28	3.09	0.14	4.51
SOUTHERN REGION:				
36 Alabama Great Southern	0.95	1.92	0.10	2.97
37 Atlantic Coast Line	1.01	1.27	0.08	2.36
38 Central of Georgia	0.90	1.48	0.08	2.46
39 Cincinnati, New Orleans & Tex. Pac.	0.89	1.99	0.09	2.97
40 Clinchfield	1.13	2.38	0.11	3.62
41 Florida East Coast	1.05	1.52	0.08	2.65
42 Gulf, Mobile & Ohio	0.97	1.91	0.09	2.97
43 Illinois Central	0.99	1.74	0.09	2.82
44 Louisville & Nashville	1.08	1.93	0.10	3.11
45 Nashville, Chattanooga & St. Louis	1.07	0.94	0.07	2.08
46 Norfolk Southern	1.16	1.31	0.10	2.57
47 Seaboard Air Line	1.17	1.69	0.10	2.96
48 Southern	1.02	1.69	0.09	2.80

a Includes freight proportion of charges to operating expense Accounts 392, 393 and 401.
b Includes freight proportion of charges to operating expense Accounts 308, 311, 394 to 400, inclusive, and 402.
c Payroll taxes calculated at rate of 5.50 per cent. Reduction from actual rate of 6.75 per cent account compensation in excess of $300 per month.

TABLE II—Continued

Railroad	Road freight train crews' wages a	Fuel, supplies, enginehouse expense and locomotive repairs b	Payroll taxes on crew wages and labor applicable to locomotive repairs and shop and enginehouse expense c	Total
NORTHWESTERN REGION:				
49 Chicago & North Western	$1.18	$1.70	$0.09	$2.97
50 Chicago Great Western	1.05	1.37	0.07	2.49
51 Chicago, Milwaukee, St. Paul & Pac.	1.15	1.87	0.09	3.11
52 Chicago, St. Paul, Mpls. & Omaha	1.08	1.68	0.08	2.84
53 Duluth, Missabe & Iron Range	2.14	4.26	0.20	6.60
54 Great Northern	1.20	1.84	0.10	3.14
55 Minneapolis & St. Louis	1.12	1.30	0.09	2.51
56 Mpls.,St.Paul&SaultSte.Marie(Incl.Wis.C.)	1.09	1.53	0.09	2.71
57 Northern Pacific	1.27	2.20	0.11	3.58
58 Spokane, Portland & Seattle	1.47	1.45	0.10	3.02
CENTRAL WESTERN REGION:				
59 Atchison, Topeka & Santa Fe Sys.	1.03	1.54	0.08	2.65
60 Chicago, Burlington & Quincy	1.03	1.39	0.08	2.50
61 Chicago, Rock Island & Pacific	1.09	1.28	0.08	2.45
62 Colorado & Southern	1.09	1.73	0.09	2.91
63 Denver & Rio Grande Western	1.31	2.57	0.12	4.00
64 Fort Worth & Denver	1.05	1.50	0.08	2.63
65 Northwestern Pacific	1.98	1.44	0.13	3.55
66 Southern Pacific	1.50	2.49	0.13	4.12
67 Union Pacific	1.20	2.37	0.11	3.68
68 Western Pacific	1.22	1.57	0.09	2.88
SOUTHWESTERN REGION:				
69 Gulf Coast Lines	1.14	1.30	0.09	2.53
70 International-Great Northern	1.08	1.38	0.09	2.55
71 Kansas City Southern	0.98	1.71	0.08	2.77
72 Louisiana & Arkansas	0.94	1.18	0.07	2.19
73 Missouri-Kansas-Texas	0.92	1.27	0 07	2.26
74 Missouri Pacific	1.06	1.51	0.09	2.66
75 Frisco Lines	1.00	1.52	0.08	2.60
76 St. Louis Southwestern	1.07	1.19	0.08	2.34
77 Texas & New Orleans	1.05	1.71	0.09	2.85
78 Texas & Pacific	1.00	1.28	0.07	2.35
Composite Average	1.19	1.96	0.10	3.25
AVERAGES BY REGIONS:				
New England	1.20	1.81	0.10	3.11
Great Lakes	1.19	1.97	0.10	3.26
Central Eastern	1.47	2.54	0.13	4.14
Pocahontas	1.12	2.63	0.11	3.86
Southern	1.03	1.68	0.09	2.80
Northwestern	1.20	1.87	0.10	3.17
Central Western	1.20	1.94	0.10	3.24
Southwestern	1.03	1.47	0.08	2.58

a Includes freight proportion of charges to operating expense Accounts 392, 393 and 401.
b Includes freight proportion of charges to operating expense Accounts 308, 311, 394 to 400, inclusive, and 402.
c Payroll taxes calculated at rate of 5.50 per cent. Reduction from actual rate of 6.75 per cent account compensation in excess of $300 per month.

Change

The change in train time results in an accompanying change in locomotive time, from which may be computed the locomotive saving. Obviously, this information is obtained from the graphic train charts.

In other words, the elimination of train interference and getting the train over the road in less time releases the locomotive that much sooner, with a resultant increase in the degree of utilization, and, if great enough, a possible cut in the locomotive pool required to handle a given number of trains

Basically

$$\text{Locomotives saved} = \frac{\text{locomotive hours saved per period}}{\text{hours per period}}$$

which may be stated in the following ways:

$$\text{Locomotives saved} = \frac{\text{locomotive hours saved per day}}{\text{hours per day}}$$

$$\text{Locomotives saved} = \frac{\text{locomotive hours saved per year}}{\text{hours per year}}$$

Where the locomotive hours saved are not known, and the train miles saved are known, the

$$\text{Locomotives saved} = \frac{\text{train miles saved per year}}{\text{average annual mileage per locomotive}}$$

In this case, the train miles saved equals the locomotive miles saved, and the formula is dimensionally correct.

Where the saving in locomotive hours is not sufficient to reduce the locomotive pool, the saving does provide more time in which to service the locomotives, make necessary running repairs, and, on occasions, avoid delays to trains waiting for power.

Value

The saving in operating expense for a saved locomotive hour is covered in the cost of a train hour.

But where it is possible to reduce the locomotive pool, there is an attendant saving in annual expense, which would be the saving in the fixed charges on the capital investment for the locomotives saved.

Having found the locomotives saved, the

Capital investment saved = locomotives saved × cost of the class of locomotive saved

Typical carrying charges would be:

	Per cent
Interest on the investment	3.00
Depreciation	3.00
Taxes—40¢ per $100	0.40
Insurance—20¢ per $100 on 10%	0.02
	6.42

Note.—Each railroad should use values applicable to the specific case.

Thus, the

Annual saving = capital investment saved × per cent fixed charges

TRAIN STOPS

Change

The train time involved in train stops will naturally and inherently be contained in the train time as covered previously. In addition, the number of train stops that would be eliminated under the assumed conditions can be approximated from the graphic train charts. These have a value aside from the train time involved.

Generally speaking, a meet or pass on single track or a pass on multiple track, when switches are handled by the trainmen, involves three stops, one of which is a stop from normal speed, while the other two are stops from low speed. That is to say, the train which is to take the siding stops to open the switch to head in. This is a stop from normal road speed. It then proceeds at low speed into the siding, and stops in the clear. This is a stop from low speed. After the other train has passed by on the main track, the switch at the leaving end of the siding is opened, and the train on the siding heads out onto the main track at low speed. Then it again stops, or makes a near stop to pick up the trainman, who has closed the switch. This may be regarded as the second stop from low speed.

Although there are operating variations, conservative results will be obtained when train stops are counted in this manner, and especially in consideration of the fact that the train holding the main may arrive first and have to stop, which is a stop from normal speed.

With power-operated switches, the same meet or overtake usually required only one or the other train to stop, which is a stop from normal speed. Very often both trains are running so that neither has to stop.

With spring switches, the third stop or the second from low speed, would not be required.

Value (Cost)

The value of the saving that results from the elimination of a train stop from the payroll viewpoint is covered under "Payroll" and from the train time viewpoint is covered under "Train Hour," but, in addition, there is the cost (fuel) of restoring the kinetic energy of motion which is dissipated or wasted in making the stop.

Since a fuel item is included in both the train hour value (cost) and the train stop value (cost), there is some duplication in the annual expense. In other words, the fuel item included in the train hour value (cost) is a statistical cost which includes all the fuel used in all ways, including stops, in connection with the production of freight train hours. Thus, in this statistical value, the portion of fuel used in accelerating trains after making stops is distributed greatly, and is probably only a small part of the total fuel item. It would be quite difficult, if not impossible, to compute the stop portion of the fuel and deduct it from the train hour value; furthermore, it is reasonable to assume that this represents a small part of the worth of intangible items in a train hour.

STEAM POWER

For steam locomotive power, the kinetic energy or work wasted for various weight trains stopping from various speeds on tangent level track

with 45-ton cars (including lading) hauled by a 2-8-2 locomotive,
with 45-ton cars (including lading) hauled by a 2-8-4 locomotive,
with 45-ton cars (including lading) hauled by a 2-10-4 locomotive, and
with 80-ton cars (including lading) hauled by a 2-10-4 locomotive

has been computed and plotted on charts, A.A.R. Sig. Sec. 7059, 7060, 7061 and 7062. See folded sheets following this page.

In addition, a procedure is later outlined whereby a chart may be prepared for any locomotive hauling any weight train with any average weight of car at various speeds.

The work wasted is then evaluated by means of the following formulas:

1. Cost of fuel wasted making stop, in dollars =

(a) Coal fired

$$\frac{0.00085 \times \text{work wasted} \times \text{S.F.} \times \text{H.C.} \times \text{cost of coal}}{\text{Calorific value of coal}} \quad (1\text{-a})$$

(b) Oil fired

$$\frac{0.0044 \times \text{work wasted} \times \text{S.F.} \times \text{H.C.} \times \text{cost of oil}}{\text{Calorific value of oil}} \quad (1\text{-b})$$

2. Cost of fuel consumed while standing, in dollars =

(a) Coal fired

$$0.000125 \times \text{grate area} \times \text{standing time} \times \text{cost of coal} \quad (2\text{-a})$$

(b) Oil fired

$$0.01 \times \text{standing time} \times \text{cost of oil} \quad (2\text{-b})$$

3. Cost of water wasted, in dollars =

$$0.00000133 \times \text{work wasted} \times \text{S.F.} \times \text{cost of water} \quad (3)$$

Total cost of fuel and water wasted making stop =

Coal fired = 1-a + 2-a + 3
Oil fired = 1-b + 2-b + 3

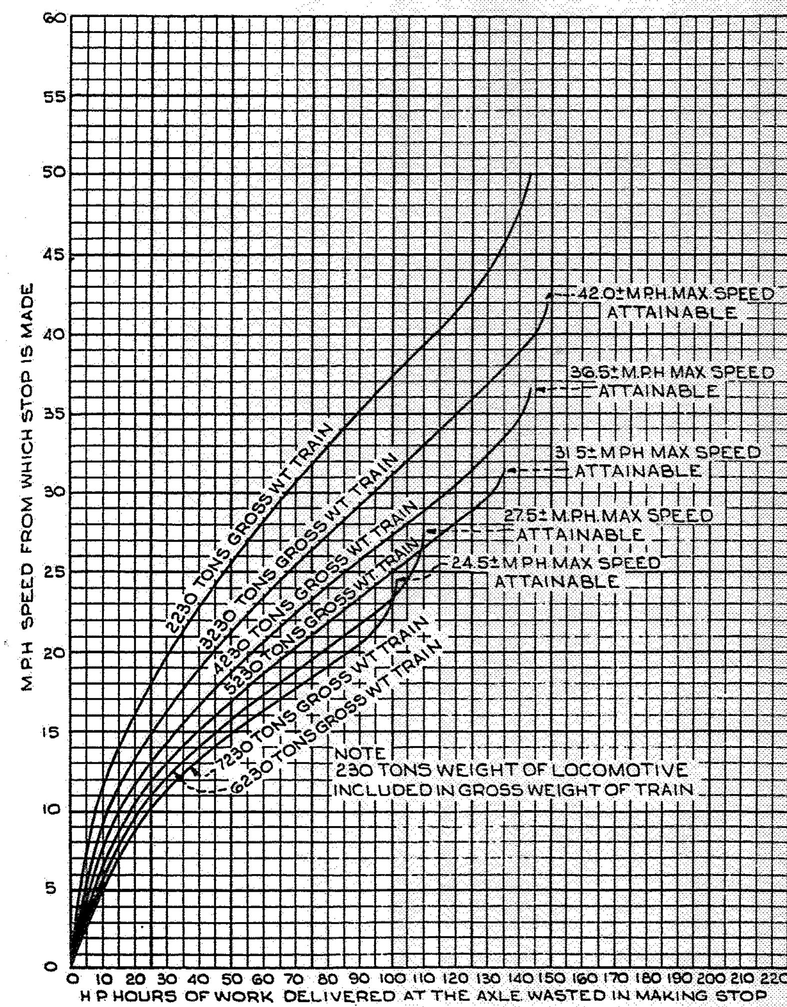
In the above

Work wasted = work wasted in driver axle horsepower hours. Obtain from chart, A.A.R. Sig. Sec. 7059, 7060, 7061 or 7062, or as computed.

S.F. = steam factor in pounds of steam per indicated horsepower hour.
Obtain from Tables III or IV, Locomotive Steam Factors (Steam rates for various pressures and temperatures).

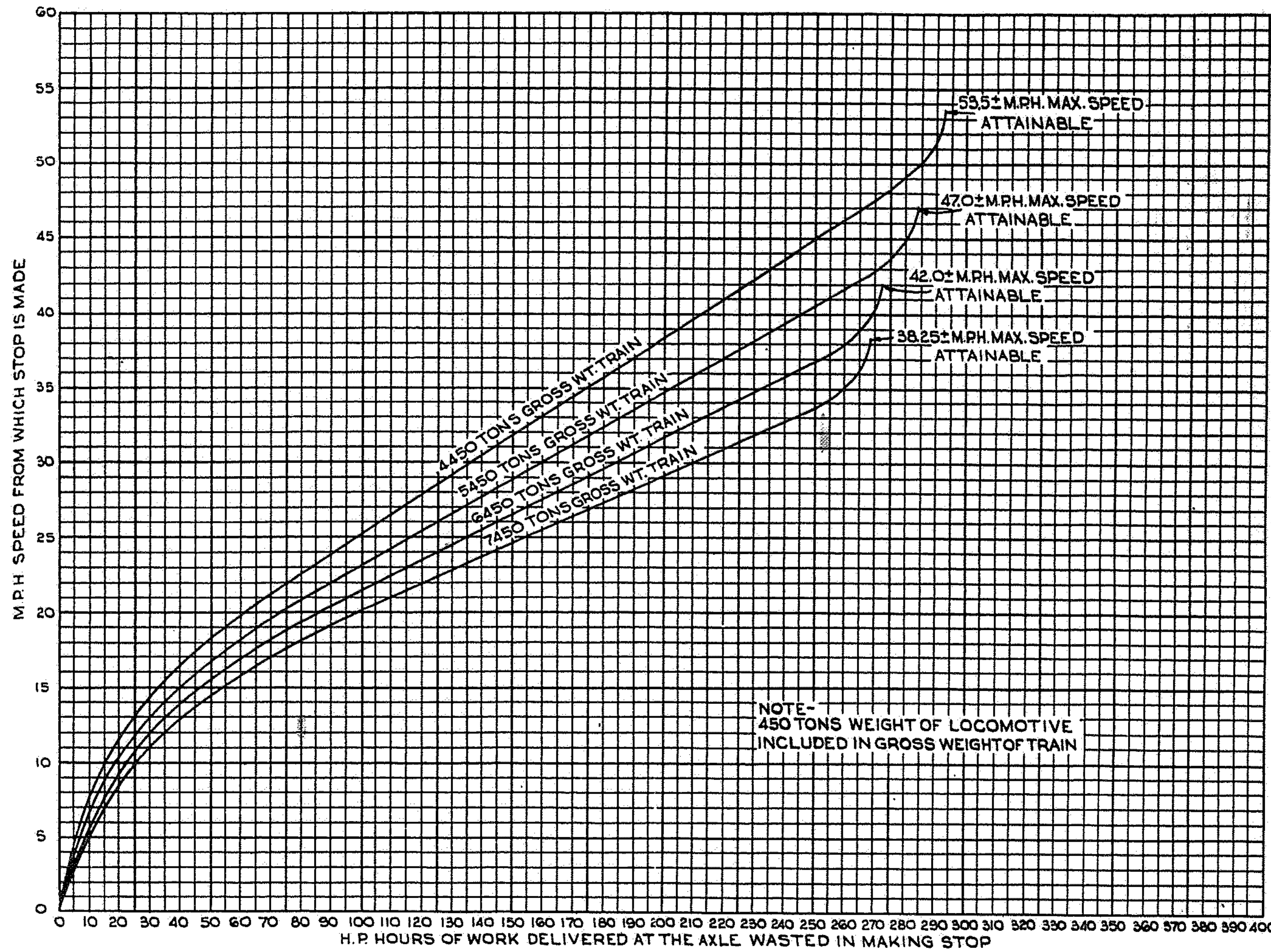
H.C. = heat content of steam in B.T.U.'s per pound. Obtain from either Table III, Properties of Saturated Steam or Table IV, Properties of Superheated Steam.

Cost of coal = cost of coal on the locomotive tender, in dollars per ton.



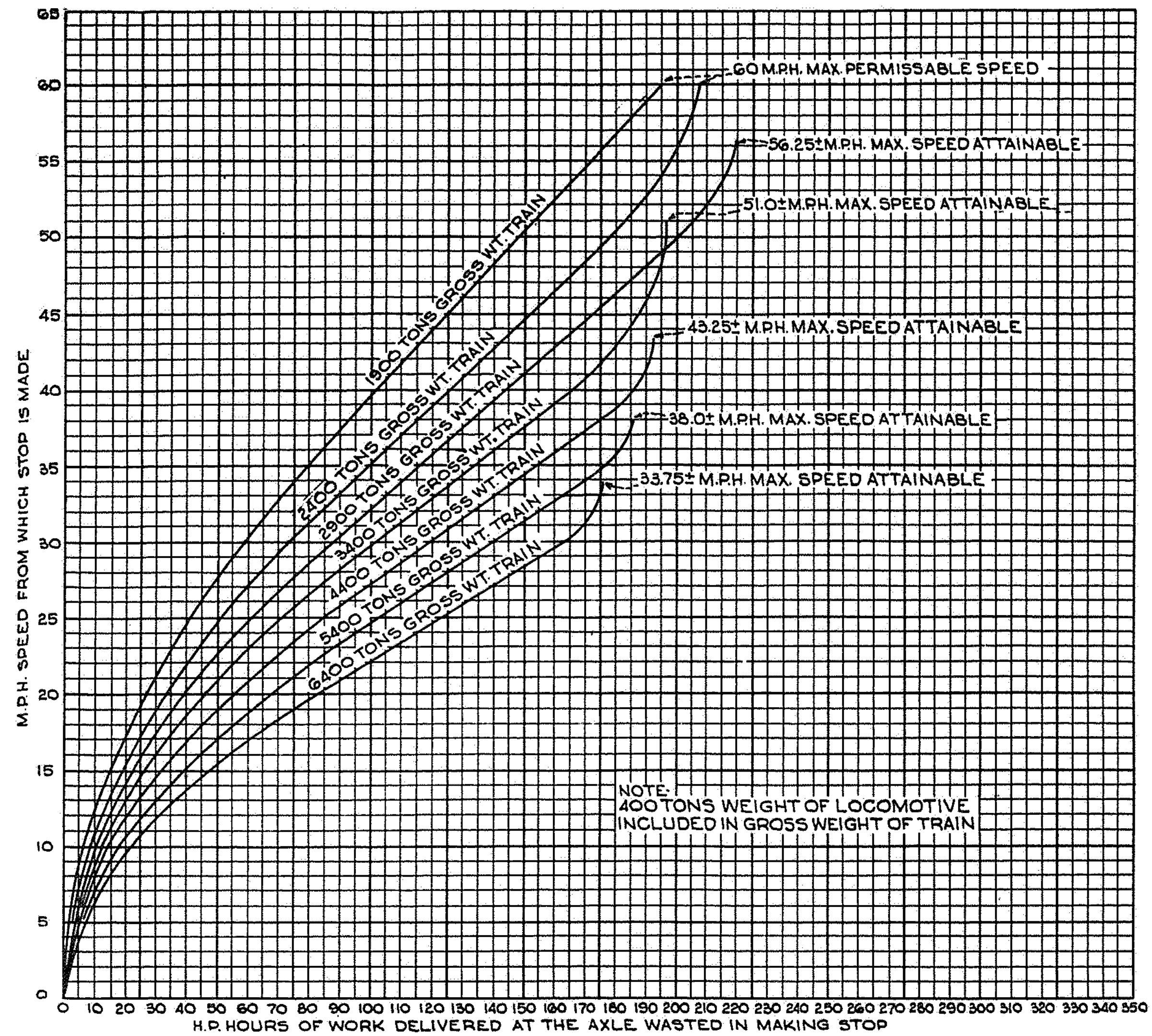
HORSEPOWER HOURS WASTED IN STOPPING VARIOUS WEIGHT TRAINS OF 45-TON DOUBLE TRUCK CARS HAULED BY 2-8-2 LOCOMOTIVE ON LEVEL TANGENT TRACK

AAR SIG. SEC. 7059 MAR. 1939



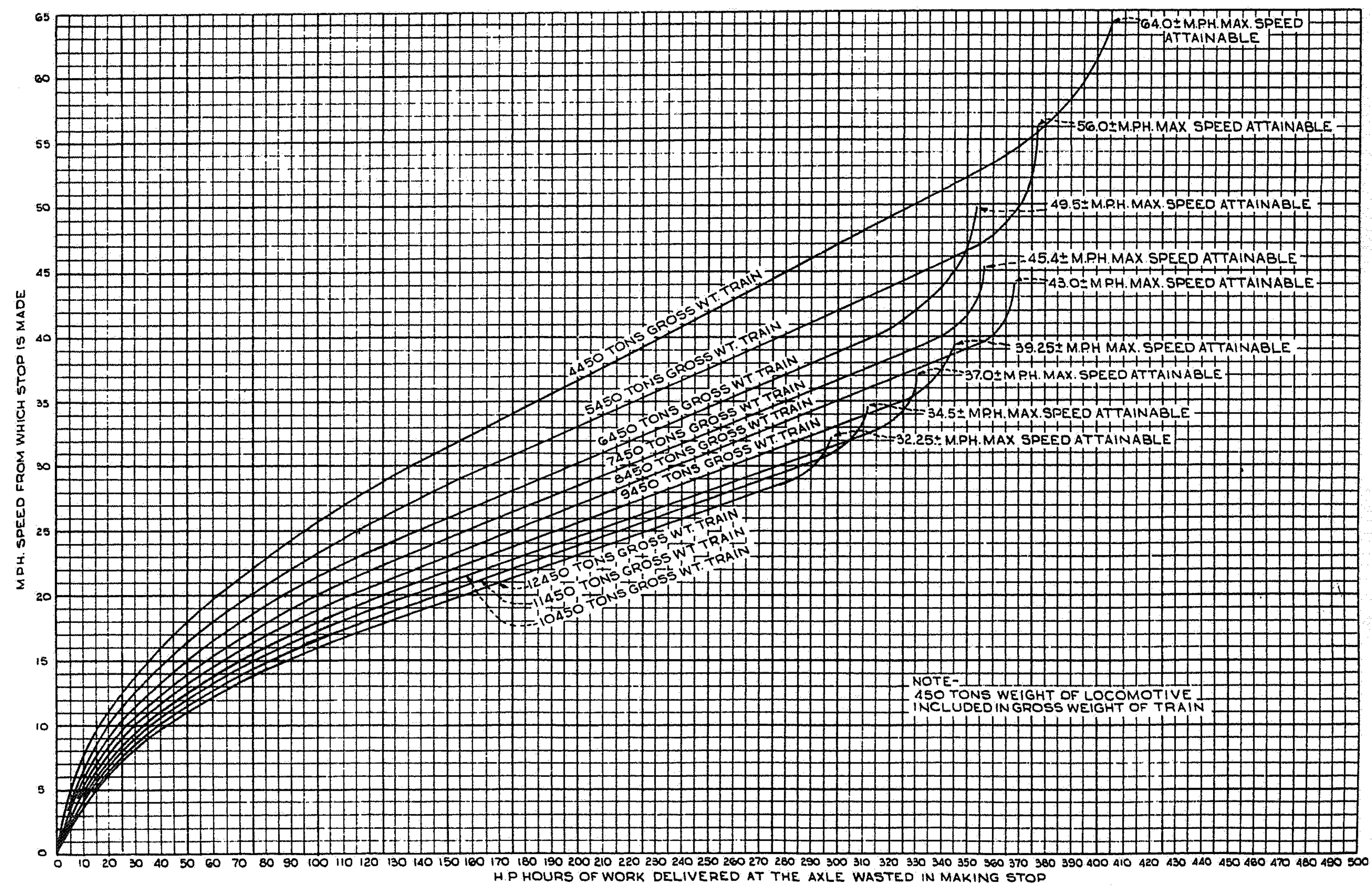
HORSEPOWER HOURS WASTED IN STOPPING VARIOUS WEIGHT TRAINS OF 45-TON DOUBLE TRUCK CARS HAULED BY 2-10-4 LOCOMOTIVE ON LEVEL TANGENT TRACK

AAR SIG. SEC. 7060 MAR. 1939



HORSEPOWER HOURS WASTED IN STOPPING VARIOUS WEIGHT TRAINS OF 45-TON DOUBLE TRUCK CARS HAULED BY 2-8-4 LOCOMOTIVE ON LEVEL TANGENT TRACK

A.A.R. SIG. SEC. 7061 MAR. 1939



HORSEPOWER HOURS WASTED IN STOPPING VARIOUS WEIGHT TRAINS OF 80-TON DOUBLE TRUCK CARS HAULED BY 2-10-4 LOCOMOTIVE ON LEVEL TANGENT TRACK

A.A.R. SIG. SEC. 7062 MAR 1939

Cost of oil = cost of fuel oil on the locomotive tender, in dollars per barrel of 42 gallons.

Calorific value of coal = heating value of coal in B.T.U.'s per pound.

Calorific value of fuel oil = heating value of fuel oil in B.T.U.'s per pound.

Grate area = grate area of locomotive fire box in square feet.

Standing time = time in minutes required to restore air pressure—not to exceed 10 minutes.

Cost of water = cost of water on the tender in cents per thousand gallons.

Additional data required:

Wheel arrangement of locomotive, 2-8-2, 2-8-4, 2-10-4

Gross weight of the train in tons

Speed from which the stop is made in miles per hour

Steam pressure in pounds per square inch gage

Steam temperature in degrees Fahrenheit. Required only when locomotive has a superheater

TABLE III

Properties of Saturated Steam and Locomotive Steam Factors

Boiler pressure lbs. per sq. in. gage (above atmosphere)	Temperature of steam, degrees F.	Total heat B.T.U.'s per pound (from 32°)	Steam factor, pounds of steam per I.H.P. hour
175	377.6	1197.0	28.75
180	379.7	1197.4	28.60
185	381.8	1197.8	28.40
190	383.9	1198.1	28.30
195	385.9	1198.4	28.10
200	387.9	1198.7	28.00
205	389.9	1199.0	27.80
210	391.8	1199.3	27.75
215	393.7	1199.6	27.60
220	395.6	1199.8	27.50
225	397.4	1200.1	27.40
230	399.2	1200.3	27.30
235	401.0	1200.5	27.20
240	402.7	1200.8	27.10
245	404.4	1201.0	27.00
250	406.1	1201.2	26.90
260	409.4	1201.6	
270	412.7	1201.9	
275			26.60
280	415.8	1202.2	
290	418.8	1202.6	
300	421.8	1202.9	26.30
325	429.0	1203.4	26.00
350	435.7	1203.8	25.80
375	442.1	1204.0	25.70
400	448.2	1204.1	25.60
425	454.0	1204.1	
450	459.6	1204.0	
475	464.9	1203.8	
500	470.0	1203.6	

TABLE IV

Properties of Superheated Steam and Locomotive Steam Factors

Boiler pressure, lbs. per sq. in. gage (above atmosphere)	Superheat, degrees F.	Temperature of steam, degrees F.	Total heat B.T.U.'s per pound (above 32°)	Steam factor, pounds of steam per I.H.P. hour
175	150	527.6	1283.7	21.65
	200	577.6	1309.9	20.40
	250	627.6	1325.5	19.30
	300	677.6	1361.9	
	350	727.6	1388.2	
180	150	529.7	1284.3	21.45
	200	579.7	1310.6	20.25
	250	629.7	1336.6	19.20
	300	679.7	1362.8	
	350	729.7	1389.0	
185	150	531.8	1285.0	21.30
	200	581.8	1311.2	20.10
	250	631.8	1337.4	19.05
	300	681.8	1363.6	
	350	731.8	1389.9	
190	150	533.9	1285.6	21.25
	200	583.9	1312.0	19.30
	250	633.9	1338.2	18.90
	300	683.9	1364.4	
	350	733.9	1391.3	
195	150	535.9	1286.2	21.10
	200	585.9	1312.6	19.80
	250	635.9	1338.9	18.80
	300	685.9	1365.2	
	350	735.9	1391.5	
200	150	537.9	1286.9	21.00
	200	587.9	1313.3	19.70
	250	637.9	1339.7	12.70
	300	687.9	1366.0	
	350	737.9	1392.4	
205	150	539.9	1287.5	20.90
	200	589.9	1314.3	19.60
	250	639.9	1340.7	18.60
	300	689.9	1367.0	
	350	739.9	1393.4	
210	150	541.8	1288.0	20.80
	200	591.8	1314.6	19.50
	250	641.8	1341.0	18.50
	300	691.8	1367.5	
	350	741.8	1394.1	

TABLE IV—Continued

Boiler pressure, lbs. per sq. in. gage (above atmosphere)	Superheat, degrees F.	Temperature of steam, degrees F.	Total heat B.T.U.'s per pound (above 32°)	Steam factor, pounds of steam per I.H.P. hour
215	150	543.7	1288.6	20.70
	200	593.7	1315.3	19.40
	250	643.7	1341.8	18.40
	300	693.7	1368.3	
	350	743.7	1394.7	
220	150	545.6	1289.1	20.65
	200	595.6	1315.9	19.30
	250	645.6	1342.4	18.30
	300	695.6	1370.0	
	350	745.6	1395.5	
225	150	547.4	1289.6	20.55
	200	597.4	1316.4	19.25
	250	647.4	1343.0	18.25
	300	698.4	1380.2	
	350	747.4	1396.2	
230	150	549.2	1290.2	20.50
	200	599.2	1317.5	19.10
	250	649.2	1343.7	18.20
	300	699.2	1370.8	
	350	749.2	1397.0	
235	150			20.45
	200			19.05
	250			18.15
	300			
	350			
240	150	552.7	1291.2	20.35
	200	602.7	1318.1	19.00
	250	652.7	1344.9	18.10
	300	702.7	1371.7	
	350	753.7	1398.4	
245	150			20.25
	200			18.90
	250			18.00
	300			
	350			
250	150	556.1	1292.1	20.20
	200	606.1	1319.2	18.85
	250	656.1	1346.1	17.95
	300	706.1	1373.0	17.10
	350	756.1	1399.7	16.30

TABLE IV—Continued

Boiler pressure, lbs. per sq. in. gage (above atmosphere)	Superheat, degrees F.	Temperature of steam, degrees F.	Total heat B.T.U.'s per pound (above 32°)	Steam factor, pounds of steam per I.H.P. hour
255	150			
	200			
	250			17.90
	300			
	350			
260	150	559.4	1293.4	
	200	609.4	1320.8	
	250	659.4	1347.6	17.85
	300	709.4	1374.2	
	350	759.4	1401.4	
265	150			
	200			
	250			17.80
	300			
	350			
270	150	562.7	1294.0	
	200	612.7	1321.2	
	250	662.7	1348.5	17.80
	300	712.7	1375.5	
	350	762.7	1402.3	
275	150			20.00
	200			18.70
	250			17.75
	300			16.80
	350			15.95
280	150			
	200			
	250			17.75
	300			
	350			
285	150			
	200			
	250			17.75
	300			
	350			
290	150	568.8	1295.7	
	200	618.8	1323.3	
	250	668.8	1350.6	17.725
	300	718.8	1377.8	
	350	768.8	1404.8	

TABLE IV—Continued

Boiler pressure, lbs. per sq. in. gage (above atmosphere)	Superheat, degrees F.	Temperature of steam, degrees F.	Total heat B.T.U.'s per pound (above 32°)	Steam factor, pounds of steam per I.H.P. hour
295	150			
	200			
	250			17.70
	300			
	350			
300	150	571.8	1296.5	19.70
	200	621.8	1324.2	18.60
	250	671.8	1351.6	17.675
	300	721.8	1378.9	16.75
	350	771.8	1406.0	15.90
305	150			
	200			
	250			17.65
	300			
	350			
310	150			
	200			
	250			17.625
	300			
	350			
315	150			
	200			
	250			17.60
	300			
	350			
320	150			
	200			
	250			17.575
	300			
	350			
325	150	579.0	1299.0	19.50
	200	629.0	1315.3	18.50
	250	679.0	1354.6	17.55
	300	729.0	1381.6	16.70
	350	779.0	1409.3	15.85

Derivation of formulas for cost of stopping trains.

In order that one may become more familiar with the problem, judge as to the validity of the formulas and the solution of the problem, and better apply the formulas to a specific case, the derivations of the formulas are given below.

The sequence of the presentation is arranged in the order in which the subjects are introduced and the work is performed, which should assist the student without hampering the experienced engineer.

Derivation of Cost of Coal Wasted Making Stop

Cost of coal wasted making stop, in dollars

= driver axle horsepower hours wasted

This element represents the work wasted on the basis of the calculations for the charts.

$$\times \frac{\text{indicated horsepower hours}}{\text{driver axle horsepower hours}} = \frac{1}{0.90}$$

This element converts the preceding into the work at the cylinders.

It is the reciprocal of the mechanical efficiency.

While the mechanical efficiency, which accounts for the losses due to the mechanical friction of the working parts, is generally assumed to be constant and when expressed in pounds is equal to 20 × tons weight of the locomotive on the drivers, it is reasonable to assume an average value of 90 per cent for the mechanical efficiency.

$$\times \frac{\text{pounds of steam}}{\text{indicated horsepower hour}}$$

This element converts the preceding into pounds of steam.

It is the steam factor or steam rate of the locomotive, which depends upon the pressure of the steam, and, when superheated, upon the temperature of the steam.

It is obtained from Table IV.

While the steam consumption is also dependent upon the cut-off and speed, the values in the table are based upon tests and are average for the entire range of cut-off and speed.

$$\times \frac{\text{B.T.U.'s}}{\text{pound of steam}}$$

This element converts the preceding into the heat that must be transferred from the coal to the steam.

It is the heat content of the steam, which depends upon the pressure of the steam, and, when superheated, upon the temperature of the steam.

It is obtained from Table IV.

While the values in the table are above 32 degrees Fahrenheit, and the coal does not have to supply the heat content between 32 degrees and the temperature of the water in the tender, there is a slight error; however, the result is sufficiently accurate and the complication of introducing a correction factor is not justified.

$$\times \frac{\text{pound of coal}}{\text{B.T.U.'s}}$$

This element converts the preceding into the pounds of coal required to supply the heat units on the basis of perfect heat transfer.

It is the reciprocal of the calorific value of the coal.

$$\times \frac{1}{\text{boiler efficiency}} = \frac{1}{0.65}$$

This element converts the preceding into pounds of coal on the basis of actual heat transfer.

The boiler efficiency varies for each locomotive, and depends upon the construction of the steam generating portion of the locomotive and also upon the rate of firing the coal; however, 65 per cent has been assumed as an average value.

$$\times \frac{\text{ton}}{\text{pounds}} = \frac{1}{2000}$$

This element converts the preceding into tons of coal.

$$\times \frac{\text{dollars}}{\text{ton of coal}}$$

This element converts the preceding into dollars.

Thus the equation may be written

Cost of coal wasted making stop, in dollars

$$= \text{work wasted} \times \frac{1}{0.90} \times \text{steam factor} \times \text{heat content}$$
$$\times \frac{1}{\text{calorific value of coal}} \times \frac{1}{0.65} \times \frac{1}{2000}$$
$$\times \text{ cost of coal}$$

Combining constants, the general formula becomes

Cost of coal wasted making stop, in dollars

$$= \frac{0.00085 \times \text{work wasted} \times \text{S.F.} \times \text{H.C.} \times \text{cost of coal}}{\text{calorific value of coal}} \qquad \text{(1-a)}$$

Derivation of Cost of Coal Consumed While Standing

Cost of coal consumed while standing, in dollars

$= \text{grate area in square feet}$

This element represents the fire bed that must be fed.

$$\times \frac{\text{pounds of coal burned}}{\text{square foot per minute}} = 0.25$$

This element converts the preceding into pounds of coal per minute.

It is the average amount of coal consumed per square foot per minute by the hot fire existing during the standing time (while pumping up the air) as determined from observations.

$\times$ standing time in minutes

This element converts the preceding into pounds of coal.

It is the time required to pump up the air, usually from 3 to 6 minutes, but not to exceed 10 minutes.

$$\times \frac{\text{ton}}{\text{pounds}} = \frac{1}{2000}$$

This element converts the preceding into tons of coal.

$$\times \frac{\text{dollars}}{\text{ton of coal}}$$

This element converts the preceding into dollars.

Thus the equation may be written

Cost of coal consumed while standing, in dollars

$$= \text{grate area} \times 0.25 \times \text{standing time} \times \frac{1}{2000} \times \text{cost of coal}$$

Combining constants, the general formula becomes

Cost of coal consumed while standing, in dollars

$$= 0.000125 \times \text{grate area} \times \text{standing time} \times \text{cost of coal} \qquad \text{(2-a)}$$

Derivation of Cost of Water Wasted

Cost of water wasted, in dollars

= driver axle horsepower hours wasted

This element represents the work wasted on the basis of the calculations for the charts.

$$\times \frac{\text{indicated horsepower hours}}{\text{driver axle horsepower hours}} = \frac{1}{0.90}$$

This element converts the preceding into the work at the cylinders.

It is the reciprocal of the mechanical efficiency.

While the mechanical efficiency, which accounts for the losses due to the mechanical friction of the working parts, is generally assumed to be constant and when expressed in pounds is equal to 20 $\times$ tons weight of the locomotive on the drivers, it is reasonable to assume an average value of 90 per cent for the mechanical efficiency.

$$\times \frac{\text{pounds of steam}}{\text{indicated horsepower hour}}$$

This element converts the preceding into pounds of steam.

It is the steam factor or steam rate of the locomotive, which depends upon the pressure of the steam, and, when superheated, upon the temperature of the steam.

It is obtained from Table IV.

While the steam consumption is also dependent upon the cut-off and speed, the values in the table are based upon tests and are average for the entire range of cut-off and speed.

$$\times \frac{\text{gallon of water}}{\text{pounds of steam}} = \frac{1}{8.34}$$

This element converts the preceding into gallons of water.

One pound of steam equals one pound of water, and one gallon of water weighs 8.34 pounds.

$$\times \frac{1}{1000}$$

This element converts the preceding into thousands of gallons of water.

$$\times \frac{\text{cents}}{\text{thousand gallons}}$$

This element converts the preceding into cents.

It is general practice to compute the cost of water on the tender in this form.

$$\times \frac{\text{dollar}}{\text{cents}} = \frac{1}{100}$$

This eleme nt converts the preceding into dollars.

Thus the equation may be written

Cost of water wasted, in dollars

$$= \text{work wasted} \times \frac{1}{0.90} \times \text{steam factor} \times \frac{1}{8.34} \times \frac{1}{1000} \times \text{cost of water} \times \frac{1}{100}$$

Combining constants, the general formula becomes

Cost of water wasted, in dollars

$$= 0.00000133 \times \text{work wasted} \times \text{S.F.} \times \text{cost of water} \qquad (3)$$

Derivation of Cost of Oil Wasted Making Stop

Cost of oil wasted making stop, in dollars

= driver axle horsepower hours wasted

This element represents the work wasted on the basis of the computations for the charts.

$$\times \frac{\text{indicated horsepower hours}}{\text{driver axle horsepower hours}} = \frac{1}{0.90}$$

This element converts the preceding into the work at the cylinders.

It is the reciprocal of the mechanical efficiency.

While the mechanical efficiency, which accounts for the losses due to the mechanical friction of the working parts, is generally assumed to be constant and when expressed in pounds is equal to 20 × tons weight of the locomotive on the drivers, it is reasonable to assume an average value of 90 per cent for the mechanical efficiency.

$$\times \frac{\text{pounds of steam}}{\text{indicated horsepower hour}}$$

This element converts the preceding into pounds of steam.

It is the steam factor or steam rate of the locomotive, which depends upon the pressure of the steam, and, when superheated, upon the temperature of the steam.

It is obtained from Table IV.

While the steam consumption is also dependent upon the cut-off and speed, the values in the table are based upon tests and are average for the entire range of cut-off and speed.

$$\times \frac{\text{B.T.U.'s}}{\text{pound of steam}}$$

This element converts the preceding into the heat that must be transferred from the oil to the steam.

It is the heat content of the steam, which depends upon the pressure of the steam, and, when superheated, upon the temperature of the steam.

It is obtained from Table IV.

While the values in the table are above 32 degrees Fahrenheit, and the oil does not have to supply the heat content between 32 degrees and the temperature of the water in the tender, there is a slight error; however, the result is sufficiently accurate and the complication of introducing a correction factor is not justified.

$$\times \frac{\text{pound of oil}}{\text{B.T.U.'s}}$$

This element converts the preceding into the pounds of oil required to supply the heat units on the basis of perfect heat transfer.

It is the reciprocal of the calorific value of the oil.

$$\times \frac{1}{\text{boiler efficiency}} = \frac{1}{0.75}$$

This element converts the preceding into pounds of oil on the basis of actual heat transfer.

The boiler efficiency varies for each locomotive, and depends upon the construction of the steam generating portion of the locomotive and also upon the rate of firing of the oil; however, 75 per cent has been assumed as an average value.

$$\times \frac{\text{gallon of oil}}{\text{pounds}} = \frac{1}{8}$$

This element converts the preceding into gallons of oil.

The weight of a gallon of oil at 60 degrees Fahrenheit varies from 6.49 pounds at 50 degrees Baume to 8.33 pounds at 10 degrees Baume; however, 8 pounds has been assumed as an average value.

$$\times \frac{\text{barrel of oil}}{\text{gallons}} = \frac{1}{42}$$

This element converts the preceding into barrels of oil.

Oil is usually purchased on the basis of a barrel of 42 gallons.

$$\times \frac{\text{dollars}}{\text{barrel}}$$

This element converts the preceding into dollars.

Thus the equation may be written

Cost of oil wasted making stop, in dollars

$$= \text{work wasted} \times \frac{1}{0.90} \times \text{steam factor} \times \text{heat content}$$

$$\times \frac{1}{\text{calorific value of oil}} \times \frac{1}{0.75} \times \frac{1}{8} \times \frac{1}{42} \times \text{cost of oil}$$

Combining constants, the general formula becomes

Cost of oil wasted making stop, in dollars

$$= \frac{0.0044 \times \text{work wasted} \times \text{S.F.} \times \text{H.C.} \times \text{cost of oil}}{\text{calorific value of oil}} \qquad (1\text{-b})$$

Derivation of Cost of Oil Consumed While Standing

Cost of oil consumed while standing, in dollars

$$= \frac{\text{gallons of oil}}{\text{minute}} = 0.42$$

This element represents the rate at which oil is fired in a standing locomotive to maintain working steam pressure.

Tests by a railroad showed a rate of from 150 to 300 gallons in 12 hours. This is at the rate of from 0.21 to 0.42 gallon per minute.

The figure of 0.42 was selected (rather than the average) to cover the variation in locomotives and firemen.

$\times$ standing time in minutes

This element converts the preceding into gallons of oil.

It is the time required to pump up the air, usually from 3 to 6 minutes.

$$\times \frac{\text{barrel of oil}}{\text{gallons}} = \frac{1}{42}$$

This converts the preceding into barrels of oil.

Oil is usually purchased on the basis of a barrel of 42 gallons.

$$\times \frac{\text{dollars}}{\text{barrel}}$$

This element converts the preceding into dollars.

Thus the equation may be written

Cost of oil wasted while standing, in dollars

$$= 0.42 \times \text{standing time} \times \frac{1}{42} \times \text{cost of oil}$$

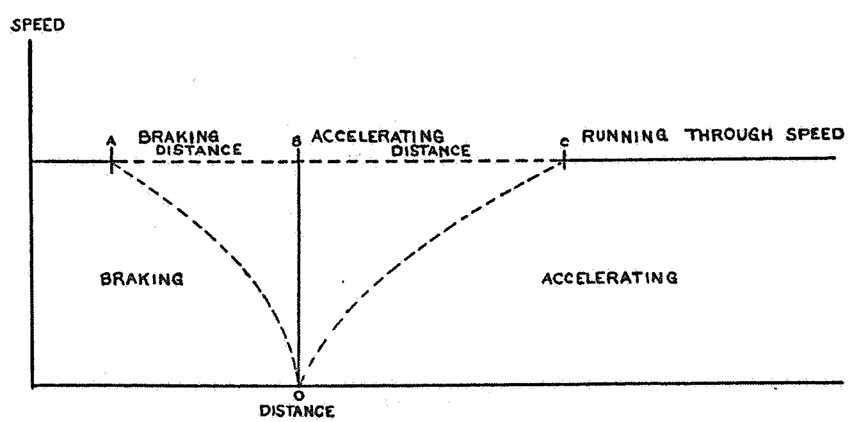
Combining constants, the general formula becomes

Cost of oil wasted while standing, in dollars

$$= 0.01 \times \text{standing time} \times \text{cost of oil} \qquad (2\text{-b})$$

Work wasted in horsepower hours vs. speed in miles per hour.

The following speed-distance diagram is the stop cycle upon which the calculations are based:



Since the stop is made by braking with open throttle, and since the driving wheels will make the same number of revolutions between "A" to "B" (running through) and "A" to "O" (stopping), the cylinders will be filled with steam the same number of times, and, without a change in the throttle and reverse lever as the train slows down, there is more time before cut-off occurs to fill the cylinders with steam than when running through; however, it is the general practice to ease off gradually on the throttle as the speed decreases and to shut it off completely just before the stop occurs.

Undoubtedly, the reduction in steam consumption due to easing off on the throttle more than compensates for the longer time of filling the cylinder—sufficiently so as to equal that used by the air pump in making up the air used in making the stop.

In view of the above, it can assumed, with little error, that the same amount of steam, and hence work, will be used between "A" to "B" (running through) and between "A" to "O" (stopping); therefore, the work wasted making the stop is the work required to be produced between "O" to "C" (accelerating) less the work required to be produced between "B" to "C" (running through).

In other words,

Work wasted making stop, in horsepower hours

= horsepower hours required from "O" to "C" to accelerate from S_o to S_B

− horsepower hours required from "B" to "C" to maintain S_B

where

horsepower hours required from "O" to "C"

= horsepower hours to overcome train resistance at progressively increasing speeds

+ horsepower hours to accelerate train from zero speed to running through speed

+ horsepower hours to overcome curve resistance

+ horsepower hours to overcome grade resistance

and,

horsepower hours required to maintain speed from "B" to "C"

= horsepower hours to overcome train resistance at running through speed

+ horsepower hours to overcome curve resistance

+ horsepower hours to overcome grade resistance

Since the curve and grade resistances are independent of the speed, and disregarding the inertia or velocity head effect in the ascent of grades because when a stop is made on a grade it is seldom that the grade is long enough to permit attaining the running through speed on it, the

horsepower hours wasted making stop

= horsepower hours to overcome train resistance at progressively increasing speeds

+ horsepower hours to accelerate train from zero speed to running through speed

− horsepower hours to overcome train resistance at running through speed

Derivation of formulas for work.

The work required to overcome either train, curve, or grade resistance is based upon the fundamental formula

work = force × distance

For Train Resistance

work = $R_T \times d$ = foot-pounds

where

$R_T = R_t \times W$ = pounds

R_t = train resistance in pounds per ton, which varies as an ascending function of the speed.

Many investigations have been made of the train resistance, and various formulas have been developed; however, it is believed that the extensive tests made by the University of Illinois in the summer of 1937 at speeds between 40 and 70 miles per hour represent the most authoritative and latest work on the subject; accordingly, the values derived by the University for trains made up of cars with average weights between 20 and 75 tons at various speeds between 5 and 70 miles per hour are shown in Table V.

W = weight of the train (including the weight of the locomotive) in tons

d = distance in feet

and since,

1 horsepower = 550 foot-pounds per second
= 33,000 foot-pounds per minute
= 1,980,000 foot-pounds per hour

thus

1 horsepower hour = 1,980,000 foot-pounds

Therefore,

$$\text{work} = \frac{R_T \times d}{1{,}980{,}000} = \text{horsepower hours}$$

$$= 0.000000505 \times R_T \times d = \text{horsepower hours}$$

or

$$\text{work} = 0.000000505 \times R_t \times d = \text{horsepower hours per ton}$$

$$= 0.000505 \times R_t \times d = \text{horsepower hours per thousand tons}$$

For Curve Resistance

work = $R_C \times d$ = foot-pounds

where

$R_C = R_c \times W$ = pounds

$R_c = 0.8 \times C$ = pounds per ton

C = curvature in degrees

TABLE V

Values of Resistance at Various Speeds and for Trains of Different Average Weights per Car

Speed miles per hour	Train Resistance—Pounds per ton — Column Headings Indicate the Average Weights Per Car												Speed miles per hour
	20 tons	25 tons	30 tons	35 tons	40 tons	45 tons	50 tons	55 tons	60 tons	65 tons	70 tons	75 tons	
5	6.8	6.0	5.4	4.8	4.4	4.0	3.7	3.5	3.3	3.2	3.1	3.0	5
6	6.9	6.1	5.5	4.9	4.4	4.1	3.8	3.5	3.3	3.2	3.1	3.0	6
7	7.0	6.2	5.5	5.0	4.5	4.1	3.8	3.6	3.4	3.2	3.1	3.1	7
8	7.1	6.3	5.6	5.0	4.6	4.2	3.9	3.6	3.4	3.3	3.2	3.1	8
9	7.2	6.4	5.7	5.1	4.6	4.2	3.9	3.6	3.4	3.3	3.2	3.1	9
10	7.3	6.5	5.8	5.2	4.7	4.3	4.0	3.7	3.5	3.3	3.2	3.2	10
11	7.4	6.6	5.9	5.3	4.8	4.3	4.0	3.7	3.5	3.4	3.3	3.2	11
12	7.5	6.7	6.0	5.4	4.8	4.4	4.0	3.8	3.6	3.4	3.3	3.3	12
13	7.6	6.8	6.1	5.5	4.9	4.5	4.1	3.8	3.6	3.5	3.4	3.3	13
14	7.8	6.9	6.2	5.5	5.0	4.5	4.2	3.9	3.7	3.5	3.4	3.4	14
15	7.9	7.0	6.3	5.6	5.1	4.6	4.2	3.9	3.7	3.6	3.5	3.4	15
16	8.0	7.1	6.4	5.7	5.1	4.7	4.3	4.0	3.8	3.6	3.5	3.5	16
17	8.1	7.2	6.5	5.8	5.2	4.8	4.4	4.1	3.9	3.7	3.6	3.5	17
18	8.3	7.4	6.6	5.9	5.3	4.8	4.5	4.1	3.9	3.7	3.7	3.6	18
19	8.4	7.5	6.7	6.0	5.4	4.9	4.5	4.2	4.0	3.8	3.7	3.6	19
20	8.5	7.6	6.8	6.1	5.5	5.0	4.6	4.3	4.0	3.9	3.8	3.7	20
21	8.7	7.7	6.9	6.2	5.6	5.1	4.7	4.3	4.1	3.9	3.9	3.8	21
22	8.8	7.9	7.0	6.3	5.7	5.2	4.8	4.4	4.2	4.0	3.9	3.8	22
23	9.0	8.0	7.1	6.4	5.8	5.3	4.9	4.5	4.3	4.1	4.0	3.9	23
24	9.1	8.1	7.3	6.6	5.9	5.4	4.9	4.6	4.3	4.2	4.1	4.0	24
25	9.3	8.3	7.4	6.7	6.0	5.5	5.0	4.7	4.4	4.2	4.1	4.0	25
26	9.4	8.4	7.5	6.8	6.1	5.6	5.1	4.8	4.5	4.3	4.2	4.1	26
27	9.6	8.5	7.7	6.9	6.2	5.7	5.2	4.8	4.6	4.4	4.3	4.2	27
28	9.7	8.7	7.8	7.0	6.3	5.8	5.3	4.9	4.7	4.5	4.4	4.3	28
29	9.9	8.8	7.9	7.1	6.5	5.9	5.4	5.0	4.8	4.6	4.5	4.4	29
30	10.0	9.0	8.0	7.3	6.6	6.0	5.5	5.1	4.9	4.7	4.5	4.5	30
31	10.2	9.1	8.2	7.4	6.7	6.1	5.6	5.2	5.0	4.8	4.6	4.5	31
32	10.4	9.3	8.3	7.5	6.8	6.2	5.8	5.3	5.0	4.9	4.7	4.6	32
33	10.5	9.4	8.5	7.6	7.0	6.3	5.9	5.4	5.2	5.0	4.8	4.7	33
34	10.7	9.6	8.6	7.8	7.1	6.5	6.0	5.5	5.3	5.1	4.9	4.8	34
35	10.9	9.7	8.8	7.9	7.2	6.6	6.1	5.7	5.4	5.2	5.0	4.9	35
36	11.1	9.9	8.9	8.0	7.4	6.7	6.2	5.8	5.5	5.3	5.1	5.0	36
37	11.2	10.0	9.0	8.2	7.5	6.9	6.4	5.9	5.6	5.4	5.2	5.1	37
38	11.4	10.2	9.2	8.3	7.6	7.0	6.5	6.0	5.7	5.5	5.3	5.2	38
39	11.6	10.4	9.4	8.5	7.8	7.1	6.6	6.2	5.8	5.6	5.4	5.3	39
40	11.8	10.6	9.5	8.6	7.9	7.3	6.8	6.3	6.0	5.7	5.6	5.5	40

TABLE V—Continued

Speed miles per hour	20 tons	25 tons	30 tons	35 tons	40 tons	45 tons	50 tons	55 tons	60 tons	65 tons	70 tons	75 tons	Speed miles per hour
	Train Resistance—Pounds per ton — Column Headings Indicate the Average Weights Per Car												
40	12.0	10.7	9.6	8.7	8.0	7.3	6.8	6.4	6.1	5.8	5.7	5.6	40
41	12.2	10.9	9.8	8.9	8.2	7.5	6.9	6.5	6.2	6.0	5.9	5.7	41
42	12.5	11.2	10.0	9.2	8.4	7.7	7.1	6.7	6.4	6.2	6.0	5.8	42
43	12.8	11.5	10.3	9.4	8.6	7.9	7.3	6.9	6.6	6.4	6.2	6.0	43
44	13.1	11.8	10.6	9.6	8.8	8.1	7.5	7.1	6.8	6.6	6.4	6.2	44
45	13.5	12.1	10.9	9.9	9.0	8.3	7.7	7.3	7.0	6.8	6.6	6.4	45
46	13.9	12.4	11.2	10.2	9.3	8.6	7.9	7.5	7.2	7.0	6.8	6.6	46
47	14.3	12.8	11.5	10.5	9.6	8.9	8.2	7.8	7.4	7.2	7.0	6.8	47
48	14.7	13.2	11.9	10.8	9.9	9.2	8.5	8.1	7.7	7.4	7.2	7.0	48
49	15.1	13.6	12.3	11.2	10.2	9.5	8.8	8.4	8.0	7.7	7.4	7.2	49
50	15.6	14.0	12.7	11.6	10.5	9.8	9.1	8.7	8.3	8.0	7.7	7.5	50
51	16.1	14.5	13.1	12.0	10.9	10.1	9.4	9.0	8.6	8.3	8.0	7.8	51
52	16.6	15.0	13.5	12.4	11.3	10.5	9.7	9.3	8.9	8.6	8.3	8.1	52
53	17.2	15.5	14.0	12.8	11.7	10.9	10.1	9.6	9.2	8.9	8.6	8.4	53
54	17.8	16.0	14.5	13.2	12.1	11.3	10.5	10.0	9.5	9.2	8.9	8.7	54
55	18.4	16.6	15.0	13.7	12.6	11.7	10.9	10.4	9.9	9.5	9.3	9.0	55
56	19.0	17.2	15.5	14.2	13.1	12.1	11.3	10.8	10.3	9.9	9.6	9.3	56
57	19.7	17.8	16.1	14.8	13.6	12.6	11.7	11.2	10.7	10.3	10.0	9.7	57
58	20.4	18.5	16.7	15.4	14.1	13.1	12.2	11.6	11.1	10.7	10.4	10.1	58
59	21.1	19.2	17.3	16.0	14.6	13.6	12.7	12.0	11.5	11.1	10.8	10.5	59
60	21.9	19.9	18.0	16.6	15.2	14.1	13.2	12.5	12.0	11.5	11.2	10.9	60
61	22.6	20.6	18.7	17.2	15.8	14.6	13.7	13.0	12.5	12.0	11.6	11.3	61
62	23.4	21.3	19.4	17.8	16.4	15.2	14.2	13.5	13.0	12.5	12.0	11.7	62
63	24.2	22.1	20.1	18.4	17.0	15.8	14.7	14.0	13.5	13.0	12.5	12.1	63
64	25.1	22.9	20.8	19.0	17.6	16.4	15.3	14.5	14.0	13.5	13.0	12.6	64
65	26.0	23.7	21.5	19.7	18.2	17.0	15.9	15.1	14.5	14.0	13.5	13.1	65
66	26.9	24.5	22.3	20.4	18.9	17.6	16.5	15.6	15.0	14.5	14.0	13.6	66
67	27.9	25.4	23.1	21.2	19.6	18.2	17.1	16.2	15.5	15.0	14.5	14.1	67
68	29.0	26.3	24.0	22.6	20.3	18.8	17.7	16.8	16.0	15.5	15.0	14.6	68
69	30.0	27.3	24.9	22.8	20.9	19.5	18.3	17.4	16.6	16.0	15.5	15.1	69
70	31.0	28.3	25.8	23.6	21.6	20.2	18.9	18.0	17.2	16.5	16.0	15.6	70

W = weight of train (including the weight of the locomotive) in tons

d = distance in feet

therefore,

$$\text{work} = \frac{R_C \times d}{1{,}980{,}000} = \text{horsepower hours}$$

$$= 0.000000503 \times R_C \times d = \text{horsepower hours}$$

or

$$\text{work} = \frac{0.8 \times C \times d}{1{,}980{,}000} = \text{horsepower hours per ton}$$

$$= 0.000000404 \times C \times d = \text{horsepower hours per ton}$$

$$= 0.000404 \times C \times d = \text{horsepower hours per thousand tons}$$

For Grade Resistance

$$\text{work} = R_G \times d = \text{foot-pounds}$$

where

$R_G = R_g \times W =$ pounds

$R_g = 20 \times G =$ pounds per ton

G = grade in per cent

W = weight of train (including weight of the locomotive) in tons

d = distance in feet

therefore,

$$\text{work} = \frac{R_G \times d}{1{,}980{,}000} = \text{horsepower hours}$$

$$= 0.000000505 \times R_G \times d = \text{horsepower hours}$$

or

$$\text{work} = \frac{20 \times G \times d}{1{,}980{,}000} = \text{horsepower hours per ton}$$

$$= 0.0000101 \times G \times d = \text{horsepower hours per ton}$$

$$= 0.0101 \times G \times d = \text{horsepower hours per thousand tons}$$

Of course, when the grade is decending, the work is mathematically a negative quantity.

When the grade in per cent is a "compensated" grade, i.e., the curve in degrees has been converted into equivalent grade in per cent by the formula

$$\text{equivalent grade in per cent} = \frac{0.8}{20} \times \text{curve in degrees}$$

$$= 0.04 \times \text{curve in degrees}$$

and added to the actual grade, the work required to overcome grade resistance includes the work required to overcome curve resistance.

When the grade is expressed in feet per mile, it may be converted into per cent by multiplying by the factor

$$\frac{100}{5280} = 0.0189$$

For Change in Speed

The work required to overcome the inertia, i.e., change in speed, is based upon the fundamental formula for the kinetic energy of a body in motion

$$\text{K.E.} = \frac{1}{2} mv^2$$

where

m = mass in pounds

v = velocity in feet per second

and since

$$m = \frac{w}{g}$$

where

w = weight in pounds

g = acceleration of gravity in feet per second per second

= 32.16 feet per second per second

thus

$$\text{K.E.} = \frac{1}{2} \times \frac{W}{32.16} \times v^2 = \text{foot-pounds}$$

and since

$$w = 2000\ W$$

$$v = \frac{5280\ S}{3600}$$

where

2,000 = pounds per ton

W = weight in tons

5,280 = feet per mile

3,600 = seconds per hour

S = speed in miles per hour

(*Note.*—Mathematically, velocity and speed are not the same because velocity involves both speed and direction of movement; however, since direction of movement is not pertinent to this derivation, speed may be substituted for velocity.)

therefore

$$\text{K.E.} = \frac{1}{2} \times \frac{2000\ W}{32.16} \times \left(\frac{5280\ S}{3600}\right)^2$$

$$= 66.9 \times W \times S^2 = \text{foot-pounds}$$

but this is for linear acceleration only; therefore, allowing approximately 5 per cent additional for angular acceleration of the rotating parts, the work becomes

$$K.E. = 70\ WS^2 = \text{foot-pounds}$$

In order to find the work required to increase the speed from S_1 to S_2

$$\text{work} = 70\ WS_2^2 - 70\ WS_1^2$$

$$= 70\ W\ (S_2^2 - S_1^2) = \text{foot-pounds}$$

$$= \frac{70}{1{,}980{,}000}\ W\ (S_2^2 - S_1^2) = \text{horsepower hours}$$

$$= 0.0000354\ W\ (S_2^2 - S_1^2) = \text{horsepower hours}$$

or

$$\text{work} = 0.0000354\ (S_2^2 - S_1^2) = \text{horsepower hours per ton}$$

$$= 0.0354\ (S_2^2 - S_1^2) = \text{horsepower hours per thousand tons}$$

Computation of Speed-Distance Data

In view of the various elements in the above formulas, it is apparent that, in order to determine the work for a specific train, it is necessary to compute the speed-distance data for the acceleration of that train.

There are a number of procedures which may be followed to compute these data; however, each is based upon the fundamental fact that the tractive force of the locomotive in pounds is used to overcome the train, curve, and grade resistances in pounds and the force in pounds required to accelerate the train, mathematically.

$$T.F. = R_T + R_C \pm R_G + P$$

where, as before,

$R_T = R_t \times W =$ pounds
$R_C = R_c \times W =$ pounds
$R_G = R_g \times W =$ pounds
R_t = train resistance in pounds per ton
R_c = $0.8 \times C$ = curve resistance in pounds per ton
C = curvature in degrees
R_g = $20 \times G$ = grade resistance in pounds per ton
G = grade in per cent
W = weight of train (including the weight of the locomotive) in tons
P = acceleration force in pounds, which is derived from the fundamental relation

$$\text{force} = \text{mass} \times \text{acceleration}$$

$$= \frac{w}{g} \times a - \text{pounds}$$

where

w = weight in pounds
a = acceleration in feet per second per second

g = acceleration of gravity = 32.16 feet per second per second

and since

$$w = 2000\ W$$

$$a = \frac{5280\ A}{3600}$$

where

2,000 = pounds per ton
W = weight in tons
5,280 = feet per mile
3,600 = seconds per hour
A = acceleration in miles per hour per second

therefore

$$P = \frac{2000\ W}{32.16} \times \frac{5280\ A}{3600}$$

$$= 91.2\ WA = \text{pounds}$$

but this is for linear acceleration only; therefore, allowing approximately 5 per cent additional for angular acceleration of the rotating parts, the force becomes

$$P = 96\ WA = \text{pounds}$$

While all the forces in the above elements may be converted into either acceleration or deceleration rates, working charts made therefrom, and the speed-distance data computed on a step by step differential speed basis, it is simpler, easier to understand, and probably less manual effort to make the computations by using the above formulas directly and as outlined hereafter.

A table with the following headings will facilitate the work:

S_1	S_2	S_{av}	T.F.	R_t	R_T	R_C	R_G	R_{TCG}	P	A
m.p.h.	m.p.h.	m.p.h.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	m/h/s

t	T	d	D	w_{TCG}	w_{S-S}	w_{TCGS}	W
secs.	secs.	ft.	ft.	h.p.h.	h.p.h.	h.p.h.	h.p.h.

Of course, if the train is being accelerated from rest on tangent level track, R_C and R_G are not required; however, the following procedure includes these elements for completeness.

Starting from rest, the initial speed $S_1 = 0$.

Assume a final speed S_2. Generally, steps of 5 miles per hour will give sufficiently accurate results, except as described later when it is necessary to make the distance traversed match a change in either alignment or grade.

Then $S_{av} = \dfrac{S_1 + S_2}{2}$.

On the Tractive Force vs. Speed curve of the locomotive, read the tractive force T.F. corresponding to speed S_{av}.

On the Train Resistance vs. Speed curve, or from the table, read R_t corresponding to speed S_{av}.

Compute the total train resistance $R_T = R_t \times$ weight of the train (including the weight of the locomotive) W in tons.

Compute the total curve resistance $R_C = 0.8 \times$ curvature in degrees $\times$ weight of the train (including the weight of the locomotive) W in tons. Obviously, this element applies only when the train has reached the curve.

Compute the total grade resistance $R_G = 20 \times$ grade in per cent $\times$ weight of the train (including the weight of the locomotive) W in tons. Obviously, this element applies only when the train has reached the grade, and for a decending grade it is negative.

Compute the total resistance $R_{TCG} = R_T + R_C \pm R_G$.

Then, the tractive force available for acceleration P = tractive force T.F. at speed $S_{av} - R_{TCG}$. Should P come out negative, there would be no force available for acceleration, and it would be necessary to assume a lower final speed S_2 and recompute the above.

Compute the acceleration $A = P \div 96 \times$ weight of the train (including the weight of the locomotive) W in tons.

Compute the time interval t = change in speed $S_2 - S_1 \div$ acceleration A.

Compute the distance interval $d = 1.467 \times t \times S_{av}$.

Should this distance exceed either the length of the curve or the length of the grade, it would be necessary to assume a lower final speed S_2 and recompute the above; and, should the distance again exceed either the length of the curve or the length of the grade, it would be necessary to again assume a lower final speed S_2 and recompute the above, proceeding until the distance is reasonably close to the length. Of course, when the train is being accelerated on tangent level track, this matching would not be required.

Repeat the above set of computations, with the initial speed S_1 being the previous final speed S_2 and the final speed S_2 being assumed anew, until the train either reaches the desired speed or the tractive force equals the train, and/or curve and grade, resistance, whence no force is available for acceleration and the train has reached its maximum or balancing speed.

On one of the steps, S_2 should be made equal to the critical speed, i.e., the break in the tractive force curve.

As the computations proceed, the cumulative time T and the cumulative distance D are computed.

In order to simplify the practical mechanics of the computations, complete the computation of the speed-distance data, and then compute the work interval data as follows.

Computation of Work Data

Compute the work interval required to overcome train, curve, and grade resistances $w_{TCG} = R_{TCG} \times d \times 0.000000505$.

Compute the work interval required to change speed $w_{S\text{-}S} = 0.0000354\ W\ (S_2^2 - S_1^2)$.

Compute the work interval $w_{TCGS} = w_{TCG} + w_{S\text{-}S}$.

Compute the cumulative work W.

The work interval w_{TCGS} for any step may also be computed by $0.000000505 \times$ T.F. $\times$ d.

Computation of Work Wasted Data

Assuming, for the moment, that it is desired to find the work wasted making a stop on tangent level track (in which case the curve and grade elements in the above would have been omitted) from various speeds in order to construct a Work Wasted vs. Speed curve, the computations would be as for a typical speed (15 m.p.h.) as follows:

Compute the work running through at speed S_{13} = 0.000000505 × R_t at speed S_{15} × weight W of the train (including the weight of the locomotive) × cumulative distance D required to attain speed S_{15}.

Compute the work wasted making stop from speed S_{15} = cumulative work accelerating to speed S_{15} − work running through at speed S_{15}.

Compute the last two steps for each speed.

As previously mentioned, since the curve and grade resistances are independent of the speed, and disregarding the inertia or velocity head effect in the ascent of grades because when a stop is made on a grade it is seldom that the grade is long enough to permit attaining the running through speed on it, the above will cover practically every case.

However, there may be special cases where it is desired to determine the work running through at a given speed with curves and grades.

In this case, the work running through would be computed as follows:

Work running through

= 0.000000505

× R_t at running through speed S

× weight W of the train (including the weight of the locomotive)

× cumulative distance D required to attain running through speed S

plus for each curve

0.000000404 × weight W × curvature C × length of curve

plus for each grade

0.0000101 × weight W × grade G × length of grade

Compute the work wasted making stop from speed S = work accelerating to speed S (which includes the curve and grade elements) − work running through at speed S.

Tractive Force vs. Speed

Since, in the preceding, the locomotive weight has been included in the weight of the train in order to simplify the computations, it is necessary that the tractive force be that at the driver axle. (*Note.*—The tractive force curves furnished for electric and Diesel-electric locomotives are generally the tractive force at the driver axle.)

If the Tractive Force vs. Speed curve for the specific lcomotive is not available, but the register data are available, the tractive force curve may be constructed quite easily and with sufficient accuracy for the preceding as outlined below.

The data required are:

Weight of the locomotive on the drivers in pounds

P = boiler pressure in pounds per square inch gage

C = cylinder diameter in inches

L = length of piston stroke in inches

D = diameter of driving wheels in inches

Direct heating surface in square feet

Indirect heating surface in square feet

Temperature of steam when superheated

Is locomotive equipped with a feed water heater or exhaust steam-operated feed water injector?

The limiting tractive force is dependent upon the weight of the locomotive and the adhesion, and may be computed from

$$T.F._{a} = \frac{1}{4} \times \text{weight of locomotive on the drivers}$$

At the lower speeds, and if not limited by $T.F._{a}$, the tractive force is dependent upon the capacity of the cylinders, and may be computed for any simple locomotive from the following formula. See "The Steam Locomotive," by Ralph P. Johnson, Simmons-Boardman Publishing Co. for formulas for other locomotives.

$$T.F._{c} = \frac{K \times P \times \pi C^2 \times 4L}{4 \times \pi D}$$

$$= \frac{K \times P \times C^2 \times L}{D}$$

where

P = boiler pressure in pounds per square inch gage

C = cylinder diameter in inches

L = length of piston stroke in inches

D = diameter of driving wheel in inches

K = factor to take care of the drop in pressure from the boiler to the cylinders. K × P is the theoretical mean effective pressure at starting

At starting, in the United States, K is universally taken as 85 per cent

After starting, K is dependent upon the piston speed in feet per minute, the relation being shown in the following table:

Piston speed in feet per minute	K
250	0.85
300	0.845
400	0.82
500	0.78
600	0.73
700	0.685
800	0.64
900	0.60
1,000	0.56
1,100	0.524
1,200	0.49
1,300	0.46
1,400	0.43

The piston speed in feet per minute may be computed from

$$PS = \frac{56 \times S \times L}{D}$$

where

S = speed in miles per hour
L = length of piston stroke in inches
D = diameter of driving wheel in inches

In general, it is only necessary to compute the tractive force from the above formula for speeds of 0, 5, 10, 15, and 20 miles per hour.

In order to obtain the tractive force at the driver axle, each of the above, except for 0 miles per hour, should be reduced by a constant value of 20 pounds per ton of locomotive weight on the drivers, to account for the mechanical friction of the working parts.

When the critical speed is attained, the tractive force is dependent upon the capacity of the boiler and may be computed from

$$T.F._b = \frac{375 \times \text{boiler horsepower}}{S}$$

where

boiler horsepower (on indicated horsepower basis)

= direct heating surface in square feet × 80 pounds of steam per square foot per hour

Note 1.—The "direct heating surface" is the area of the water side of the firebox, combustion chamber, arch tubes, and circulators.

Note 2.—The evaporation from the direct heating surface is dependent upon the type of boiler and furnace; however, 80 is a good average value, except in the case of very old locomotives where 55 is a good average value.

+ indirect heating surface in square feet × 10 pounds of steam per square foot per hour

Note 1.—The "indirect heating surface" is the area of the water side of the flues and tubes.

Note 2.—The evaporation from the indirect heating surface is dependent upon the spacing, diameter and length of the tubes; however, 10 is a good average value and sufficiently accurate.

÷ steam factor in pounds of steam per indicated horsepower hour

Note.—The steam factor or steam rate depends upon the pressure of the steam, and, when superheated, upon the temperature of the steam.

It is obtained from Table IV.

While the steam consumption is also dependent upon the cut-off and speed, the values in the table are based upon tests and are average for the entire range of cut-off and speed.

× 1.08

Note.—This factor is used only when the locomotive is equipped with either a feed-water heater or an exhaust steam-operated feed-water injector.

and S = speed in miles per hour.

Sufficient accuracy is obtained by computing $T.F._b$ at 10 mile per hour intervals.

In order to obtain the tractive force at the driver axle, each of the above should be reduced by a constant value of 20 pounds per ton of weight on the drivers, to account for the mechanical friction of the working parts.

DIESEL-ELECTRIC POWER

Charts have been developed (see A.A.R. Sig. Sec. 7066 through 7071, pages 63-68) for the extra fuel for a stop from various speeds of various weight trains made up of loaded cars having an average weight of 50 tons on level, + 0.2 per cent, − 0.2 per cent, − 0.4 per cent, − 0.6 per cent and − 0.8 per cent grades and tangent track.

COST OF STOPPING TRAINS

(Steam Power Example)

Train—60 loads, 5 empties
3,250 tons load

Available information:

Locomotive, Class "S-3," type 2-8-4, coal burning

Total weight of locomotive	461,470 lbs.
Weight on drivers	284,670 lbs.
Boiler pressure	225 lbs.
Heating surface	
Direct	437 sq. ft.
Indirect	5,254 sq. ft.
Superheat	250° F. (assumed)
Grate area	100.3 sq. ft.
Cylinders	
Diameter	28½ in.
Stroke	32 in.
Diameter of driving wheels	70 in.
Weight of tender, ⅔ loaded	298,530 lbs. (estimated)

Coal

Cost on tender.. $3.75 per ton

Calorific value.. 12,500 BTU/lb.

Water

Cost..10 cents per 1,000 gals.

TRACTIVE FORCE vs. SPEED (See page 53).

P	= boiler pressure, p.s.i., gage	=	225
C	= cylinder diameter, inches	=	28.5
L	= length of piston stroke, inches	=	32
D	= diameter of driving wheels, inches	=	70

Weight on drivers	=	284,670 lbs.
Direct heating surface	=	437 sq. ft.
Indirect heating surface	=	5,254 sq. ft.

Steam temperature:

using: 225 lbs. per sq. in. gage pressure, and $250°$ F. superheat

obtain from Table IV: 647.4° F.

Limiting tractive force dependent upon weight of locomotive and adhesion:

$$T.F._a = \frac{1}{4} \times 284{,}670 = 71{,}167.5 \text{ lbs.}$$

Tractive force dependent upon cylinder capacity (see page 54):

$$T.F._c = \frac{K \times P \times C^2 \times L}{D}$$

$$= \frac{K \times 225 \times (28.5)^2 \times 32}{70}$$

$$= 83{,}546 \times K$$

Values for K taken from the table on page 54, some interpolation being necessary.

Piston speeds computed as follows:

$$PS = \frac{56 \times S \times L}{D}$$

$$= \frac{56 \times S \times 32}{70}$$

$$= 25.6 \times S$$

Driver axle T.F. (except at 0 m.p.h.)

$$= T.F._c - \frac{284{,}670 \text{ lbs. on driver}}{2{,}000 \text{ lbs. per ton}} \times 20 \text{ lbs./ton}$$

$$= T.F._c - 2{,}847 \text{ lbs.}$$

TRACTIVE FORCE, Dependent upon Cylinder Capacity

S Speed, m.p.h.	PS Piston speed, ft. per min.	K	T.F.c, lbs.	Driver axle T.F., lbs.
0	0	0.85	71,014	71,014
5	128	0.85	71,014	68,167
10	256	0.85	71,014	68,167
15	384	0.824	68,842	65,995
20	512	0.774	64,665	61,818
25	640	0.708	59,151	56,304
30	768	0.657	54,890	52,043
35	896	0.600	50,128	47,281
40	1024	0.551	46,034	43,187
45	1152	0.507	42,358	39,511
50	1280	0.466	38,932	36,085
55	1408	0.43	35,925	
60	1536	0.40	33,418	

Tractive force dependent upon boiler capacity (see page 55):

$$\text{Boiler H.P.} = \frac{437 \times 80 + 5254 \times 10}{18.25} \times 1.08$$

$$= \frac{34960 + 52540}{18.25} \times 1.08$$

$$= 5178$$

$$T.F._b = \frac{375 \times 5178}{S}$$

$$= \frac{1,941,750}{S} \text{ lbs.}$$

Driver axle T.F. = $T.F._b$ - 2,847 lbs.

This reduction computed for previous tabulation.

TRACTIVE FORCE, Dependent upon Boiler Capacity

S Speed, m.p.h.	T.F.b, lbs.	Driver axle T.F., lbs.
10	194,175	
15	129,452	
20	97,089	
25	77,672	
30	64,726	
35	55,480	
40	48,545	
45	43,151	
50	38,836	35,989
55	35,305	32,458
60	32,363	29,516
65	29,874	27,027

By using the values shown on the two tabulations now completed, the Tractive Effort vs. Speed curves shown in Fig. 3 were plotted.

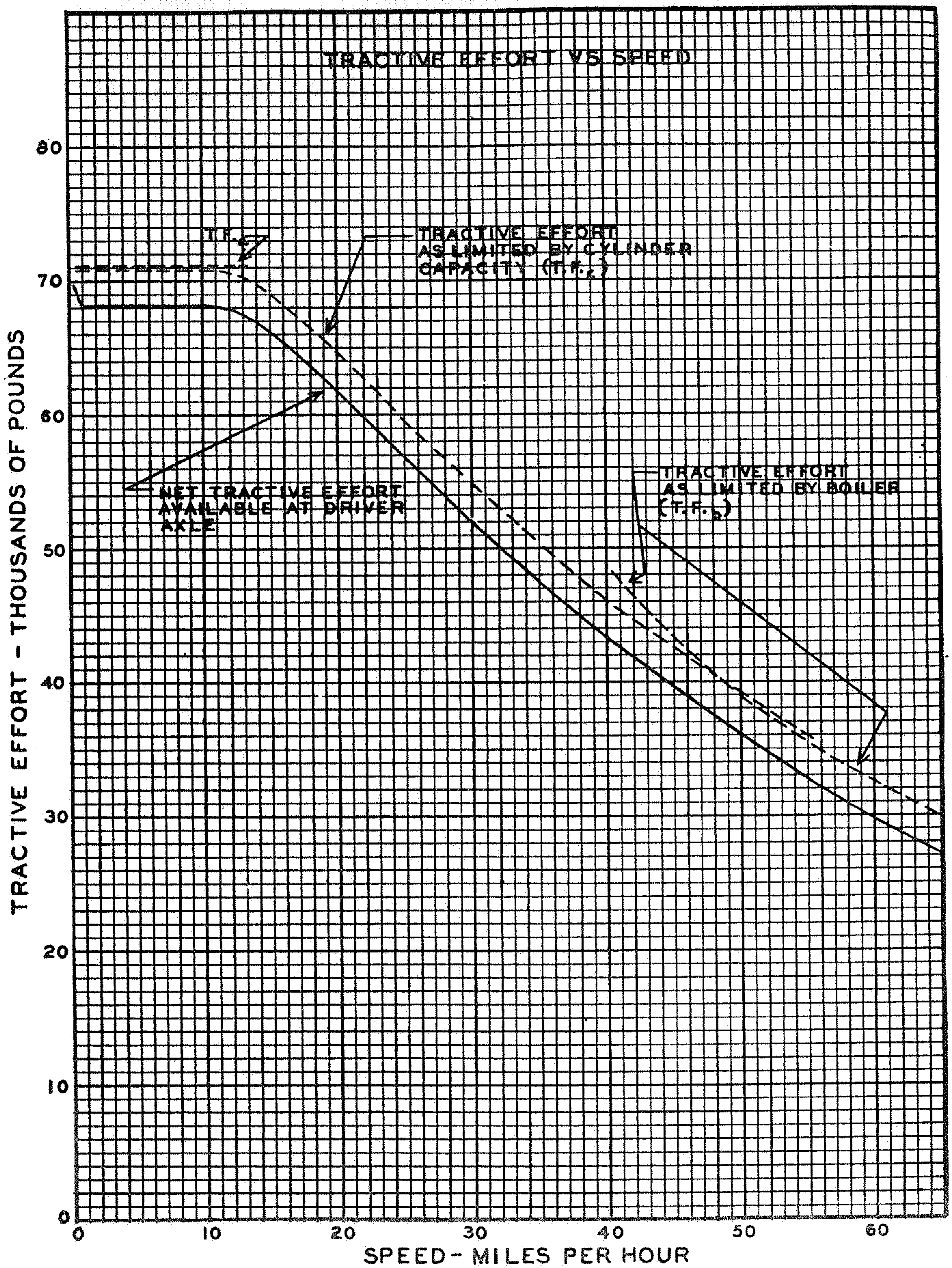

TRACTIVE EFFORT VS SPEED
T.F.c
TRACTIVE EFFORT AS LIMITED BY CYLINDER CAPACITY (T.F.c)
NET TRACTIVE EFFORT AVAILABLE AT DRIVER AXLE
TRACTIVE EFFORT AS LIMITED BY BOILER (T.F.b)
TRACTIVE EFFORT - THOUSANDS OF POUNDS
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
SPEED- MILES PER HOUR

Fig. 3.

Speed, Distance, and Work Computations. (See page 51.)

Average weight of cars in train (from consist):

60 loads
5 empties
65 cars

$$\frac{3{,}250 \text{ tons}}{65 \text{ cars}} = 50 \text{ tons per car, average}$$

Total weight of train:

Locomotive	461,470 lbs.
Tender (⅔ loaded)	298,530 lbs.
	760,000 lbs. or 380 tons

380 tons—Loco. + Tender
3,250 tons—Train (consist)
3,630 tons—Total weight of train

Speed, Distance, and Work while Accelerating

S_1 m.p.h.	S_2 m.p.h.	S_{av} m.p.h.	T.F. lbs.	R_t lbs.	R_T lbs.	P lbs.	A m/h/s	t sec.	T sec.	d ft.	D ft.	W_{ts} h.p.h.	W h.p.h.
0	5	2.5	68,167	3.7	13,431	54,736	0.1571	30.8	31	113.0	113	3.89	4
5	10	7.5	68,167	3.9	14,157	54,010	0.1550	32.3	63	355.4	468	12.23	16
10	14	12	67,800	4.0	14,520	53,280	0.1529	26.1	89	459.5	928	15.73	32
14	18	16	65,100	4.3	15,609	49,491	0.1420	28.2	117	661.9	1590	21.76	54
18	22	20	61,818	4.6	16,698	45,120	0.1295	30.9	148	906.6	2496	28.30	82
22	26	24	56,300	4.9	17,787	38,513	0.1105	36.2	185	1274.5	3771	36.24	118
26	30	28	53,700	5.3	19,239	34,461	0.0989	40.4	225	1659.5	5430	45.00	163
30	34	32	50,000	5.8	21,054	28,946	0.0831	48.1	273	2258.0	7688	57.01	220
34	38	36	46,400	6.2	22,506	23,894	0.0685	58.4	331	3084.2	10773	72.27	292
38	42	40	43,187	6.8	24,684	18,503	0.0531	75.3	407	4418.6	15191	96.37	389
42	46	44	40,200	7.5	27,225	12,975	0.0372	107.5	514	6938.9	22130	140.87	530
46	50	48	37,400	8.5	30,855	6,545	0.0187	213.9	728	15062.0	37192	284.48	814

Work Wasted. (See page 52.)

$$\text{Work running through} = 0.000\,000\,505 \times R_t \times W \times D$$
$$= 0.000\,000\,505 \times R_t \times 3630 \times D$$
$$= 0.001\,833\,15 \times R_t \times D$$

Speed, m.p.h.	(From Table V) R_t, lbs./ton	(From preceding table) D, ft.	Work running through, h.p.h.	(From preceding table) Work while accelerating, h.p.h.	Work wasted, h.p.h.
5	3.7	113	1	4	3
10	4.0	486	3	16	13
18	4.5	1,590	13	54	41
26	5.1	3,771	35	118	83
34	6.0	7,688	85	220	135
38	6.5	10,773	128	292	164
42	7.1	15,191	198	389	191
46	7.9	22,130	320	530	210
50	9.1	37,192	620	814	194

Cost of Stop.

Cost of fuel wasted making stop, in dollars (formula 1-a, page 30)

$$= \frac{0.00085 \times \text{work wasted} \times \text{S.F.} \times \text{H.C.} \times \text{cost of coal}}{\text{calorific value of coal}}$$

$$= \frac{0.00085 \times \text{work wasted} \times 18.25 \times 1343.0 \times 3.75}{12.500}$$

$$= 0.00625 \times \text{work wasted}$$

Cost of fuel wasted while standing, in dollars (formula 2-a, page 30)

$$= 0.000125 \times \text{grate area} \times \text{standing time} \times \text{cost of coal}$$

$$= 0.000125 \times 100.3 \times 6 \times 3.75$$

$$= 0.282$$

Cost of water wasted, in dollars (formula 3, page 30)

$$= 0.00000133 \times \text{work wasted} \times \text{S.F.} \times \text{cost of water}$$

$$= 0.00000133 \times \text{work wasted} \times 18.25 \times 10$$

$$= 0.000243 \times \text{work wasted}$$

Total Cost of Stop at Various Speeds

Speed, m.p.h.	Work wasted, h.p.h.	Cost of fuel wasted making stop, $	Cost of fuel wasted while standing, $	Cost of water wasted, $	Total cost of stop, $
5	3	0.019	0.282	0.001	0.30
10	13	0.081	0.282	0.003	0.37
18	41	0.256	0.282	0.010	0.59
26	83	0.519	0.282	0.020	0.82
34	135	0.844	0.282	0.033	1.16
38	164	1.025	0.282	0.040	1.35
42	191	1.194	0.282	0.046	1.52
46	210	1.313	0.282	0.051	1.65
50	194	1.213	0.282	0.047	1.54

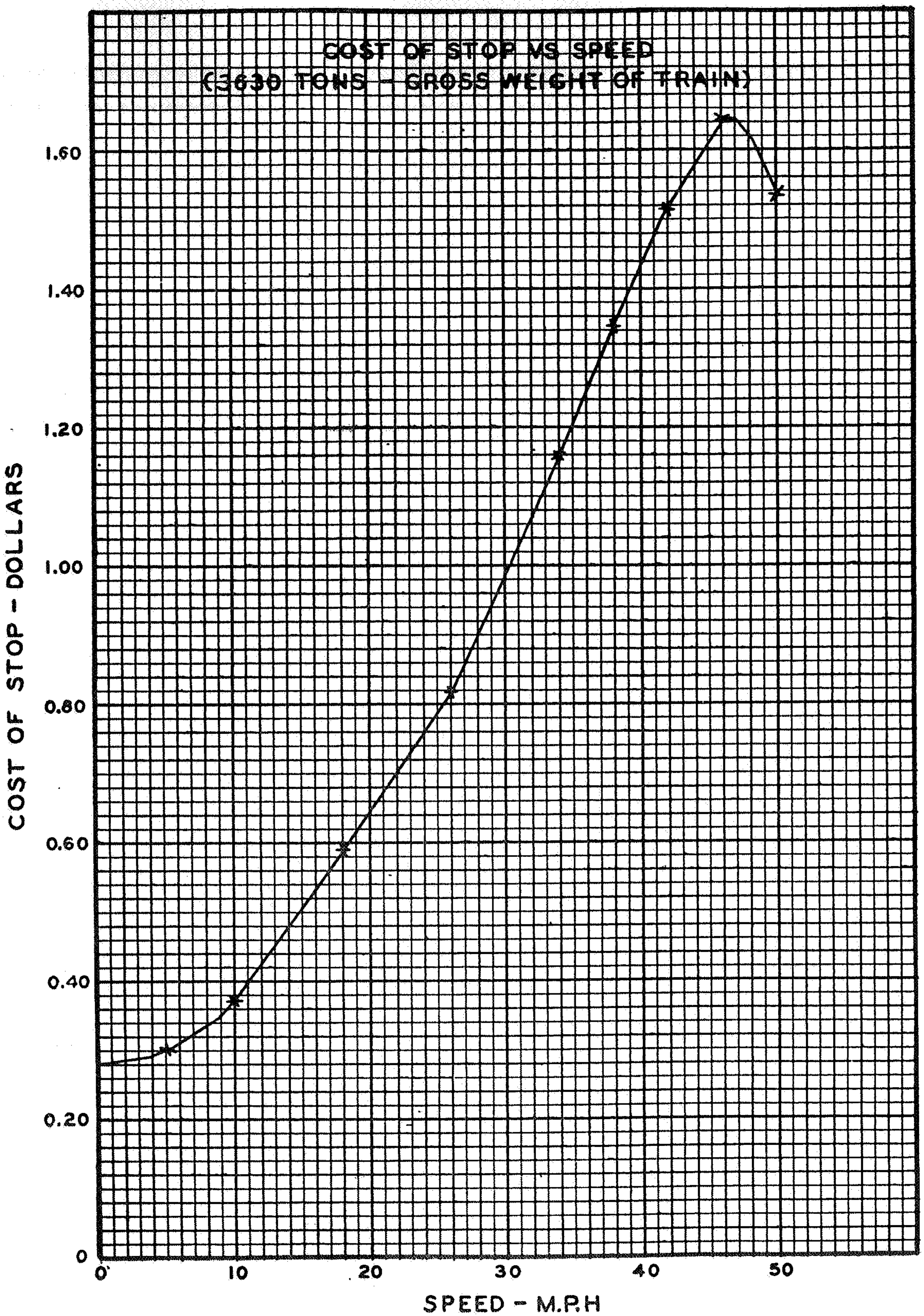
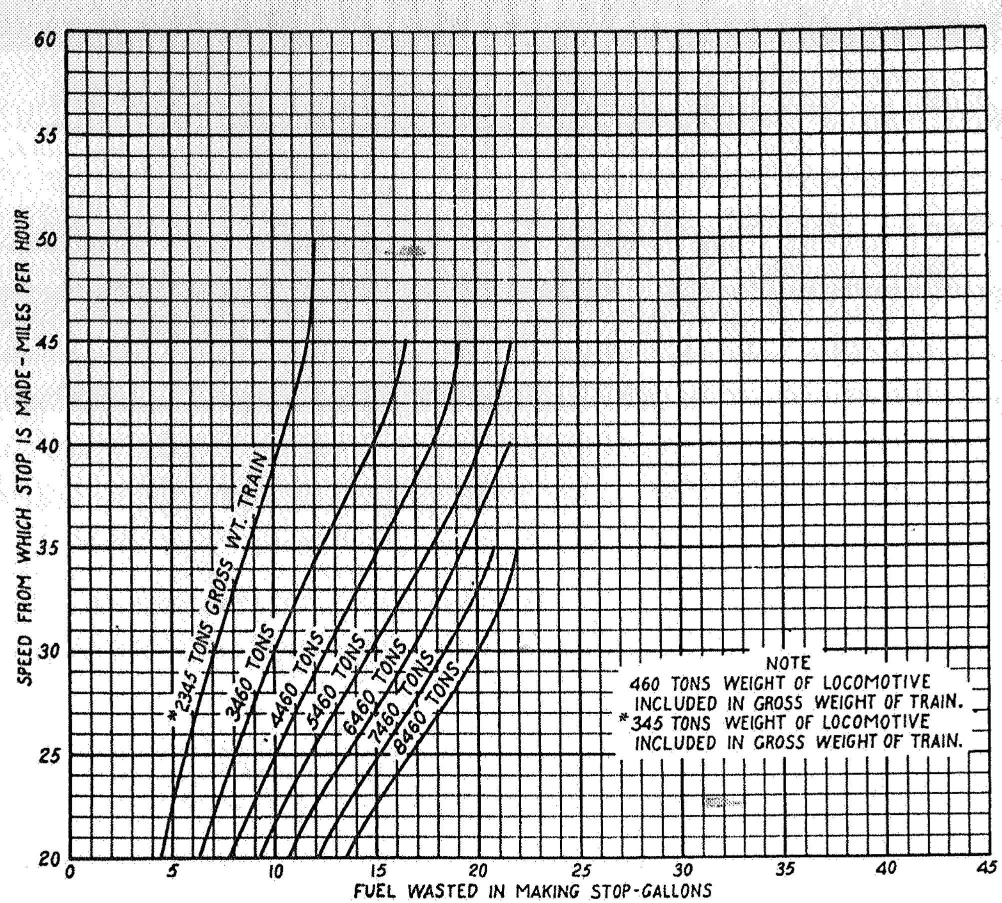
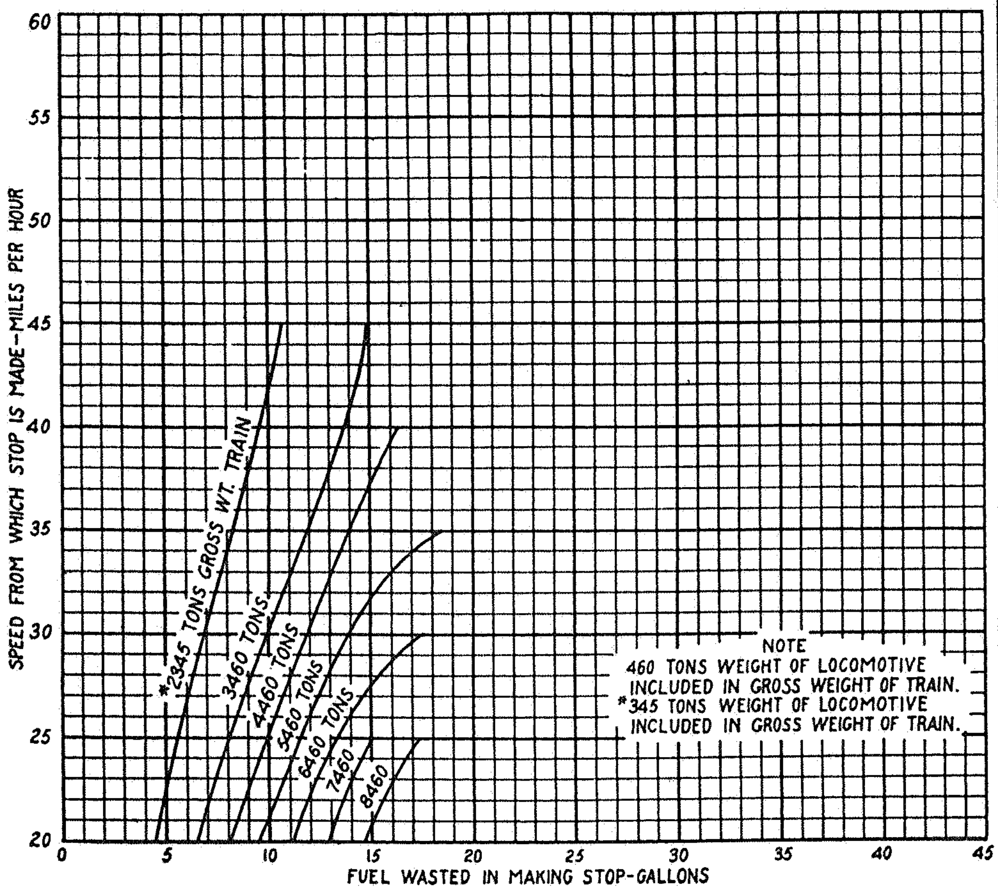

COST OF STOP VS SPEED
(3630 TONS - GROSS WEIGHT OF TRAIN)
COST OF STOP - DOLLARS
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0
0
10
20
30
40
50
SPEED - M.P.H

Fig. 4.



AAR SIG. SEC. 7066 — FUEL OIL WASTED IN STOPPING VARIOUS GROSS WEIGHT TRAINS OF 50-TON CARS HAULED BY DIESEL-ELECTRIC LOCOMOTIVES ON LEVEL TANGENT TRACK

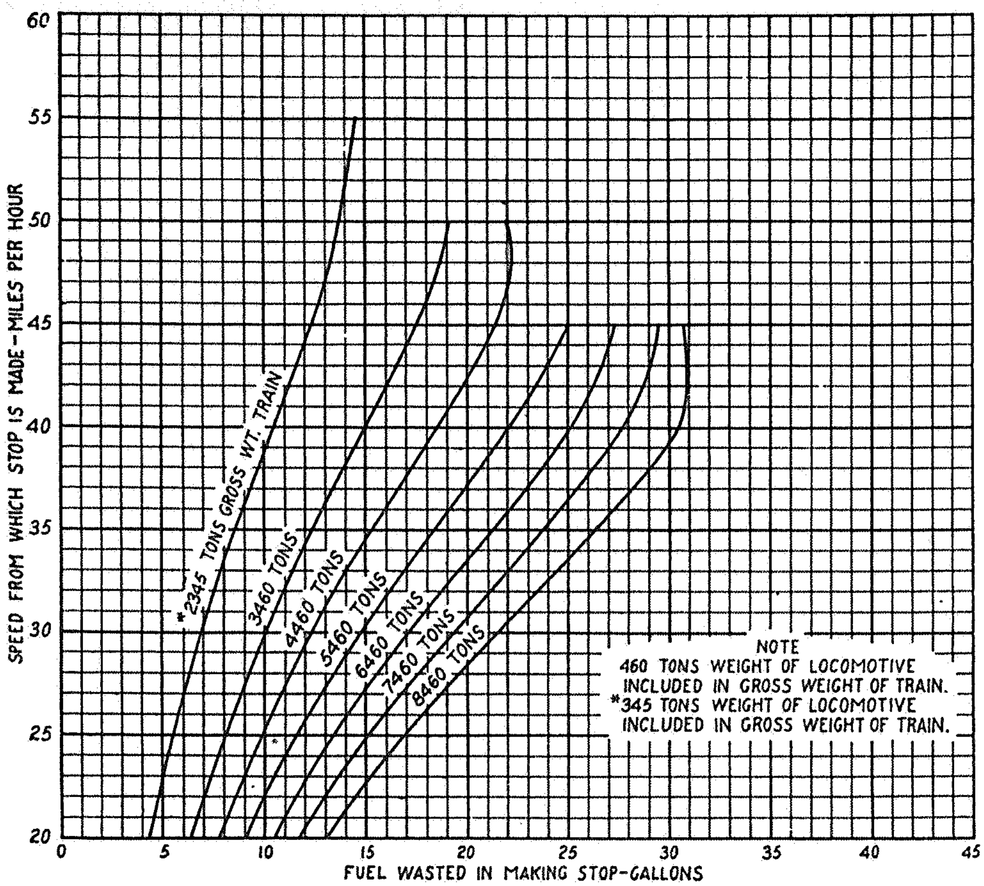
SEP. 1951



AAR SIG. SEC. 7067

FUEL OIL WASTED IN STOPPING VARIOUS GROSS WEIGHT TRAINS OF 50-TON CARS HAULED BY DIESEL-ELECTRIC LOCOMOTIVES ON PLUS 0.2 % GRADE TANGENT TRACK

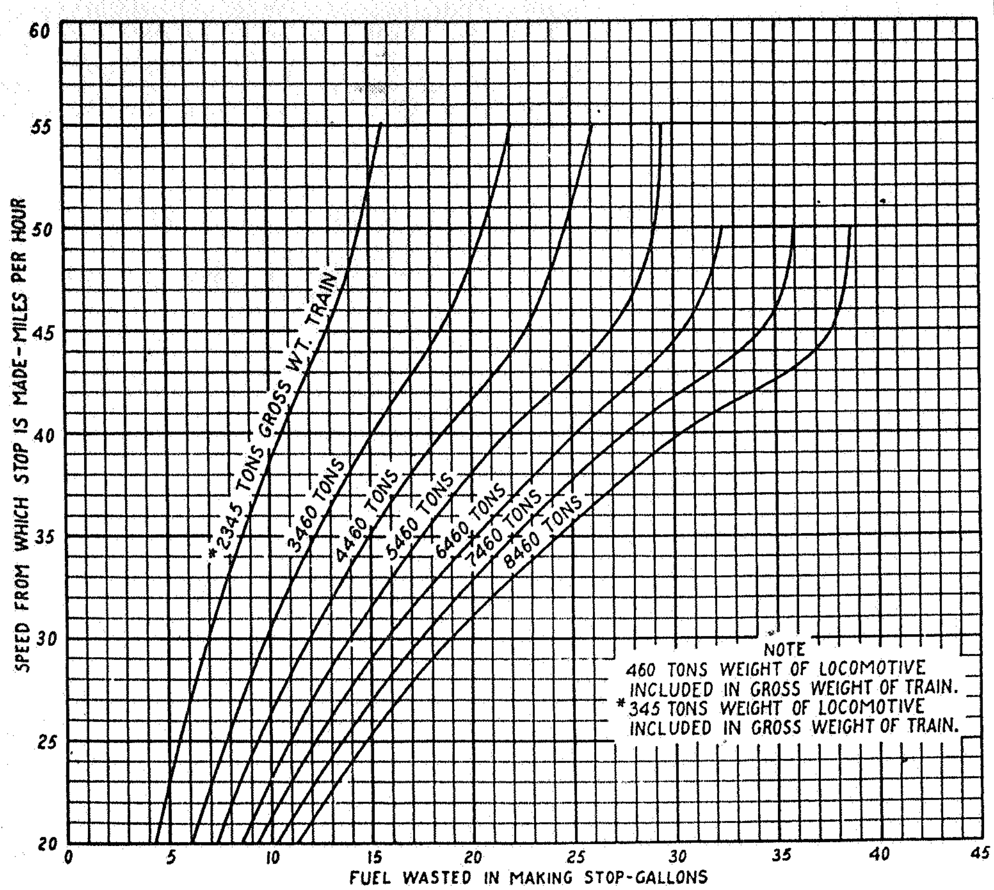
SEP. 1951



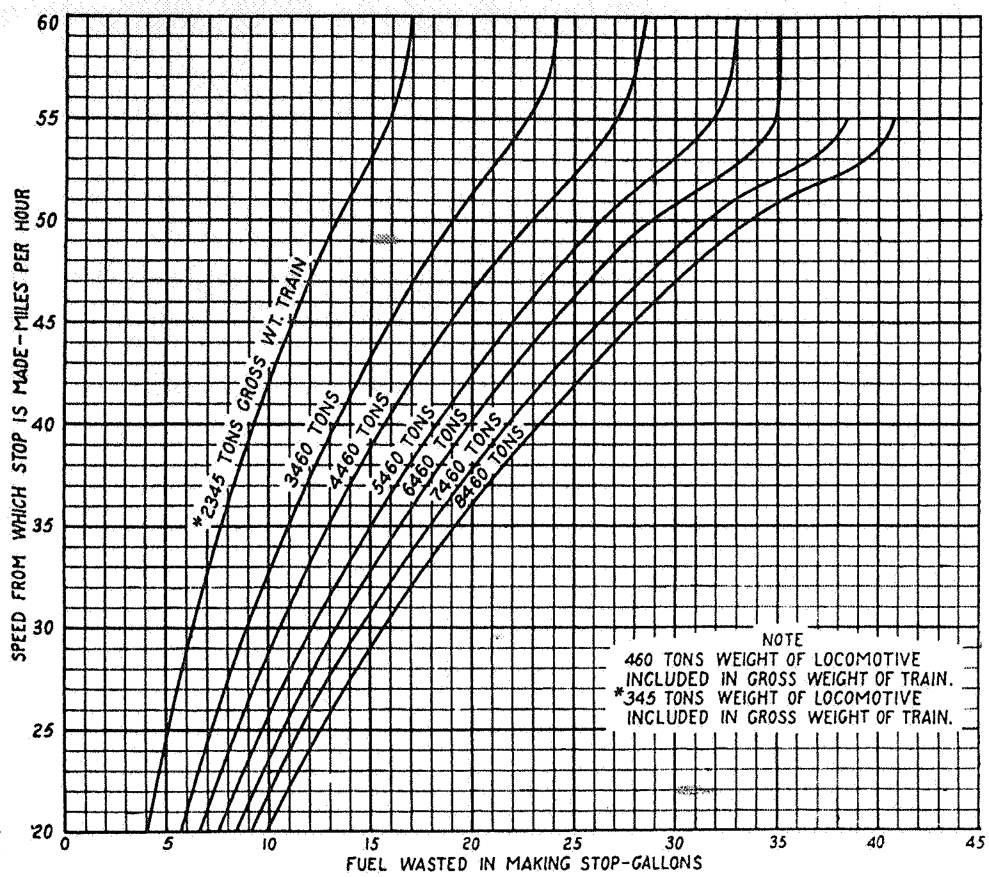
AAR SIG. SEC. 7068

FUEL OIL WASTED IN STOPPING VARIOUS GROSS WEIGHT TRAINS OF 50-TON CARS HAULED BY DIESEL-ELECTRIC LOCOMOTIVES ON MINUS 0.2 % GRADE TANGENT TRACK

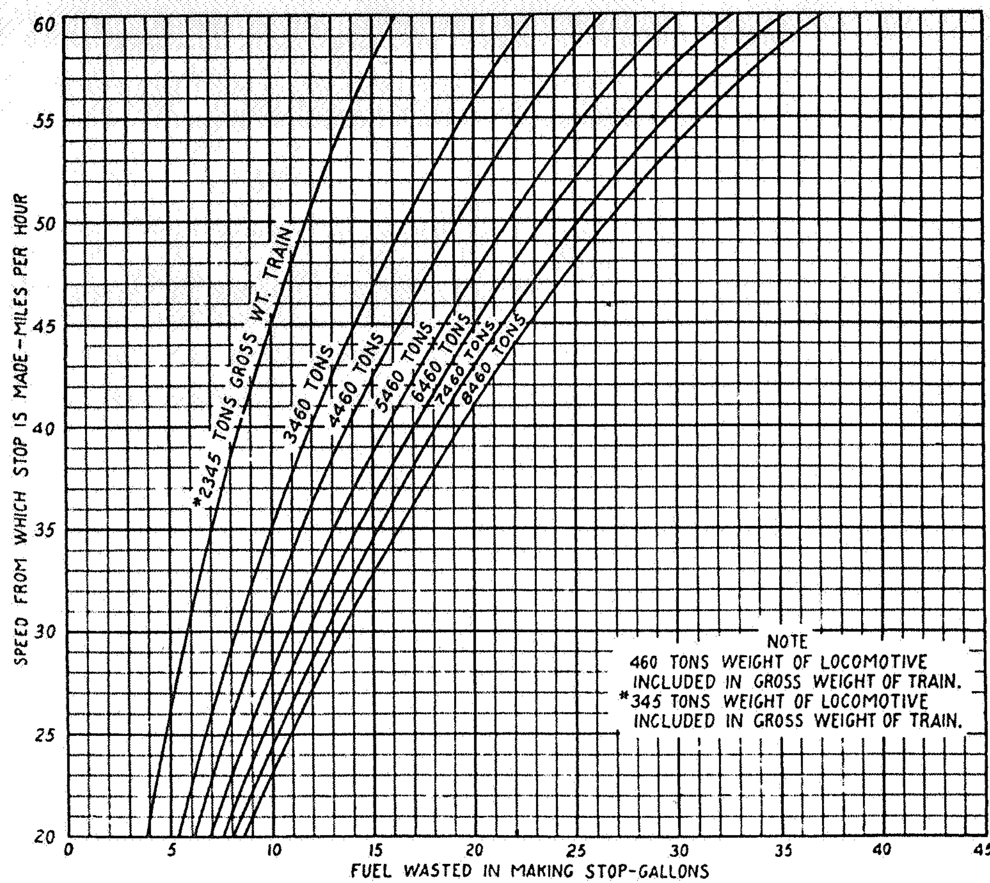
SEP. 1951



AAR SIG. SEC. 7069	FUEL OIL WASTED IN STOPPING VARIOUS GROSS WEIGHT TRAINS OF 50-TON CARS HAULED BY DIESEL-ELECTRIC LOCOMOTIVES ON MINUS 0.4 % GRADE TANGENT TRACK
	SEP. 1951



AAR SIG. SEC. 7070	FUEL OIL WASTED IN STOPPING VARIOUS GROSS WEIGHT TRAINS OF 50-TON CARS HAULED BY DIESEL-ELECTRIC LOCOMOTIVES ON MINUS 0.6 % GRADE TANGENT TRACK
	SEP. 1951



AAR SIG. SEC. 7071

FUEL OIL WASTED IN STOPPING VARIOUS GROSS WEIGHT TRAINS OF 50-TON CARS HAULED BY DIESEL-ELECTRIC LOCOMOTIVES ON MINUS 0.8 % GRADE TANGENT TRACK

SEP. 1951

These charts are based upon the following formula:

Cost of fuel wasted making stop, in dollars

= (fuel in gallons consumed while braking

+ fuel in gallons consumed while standing

+ fuel in gallons consumed while accelerating

− fuel in gallons consumed in running through at speed)

× cost of fuel in dollars per gallon

where

Fuel in gallons consumed while braking

= no load fuel consumption in gallons per hour per unit

This element represents the fuel rate per locomotive unit.

× number of units in the locomotive

This element converts the preceding into the fuel rate for the locomotive.

$$\times \frac{\text{time to stop in seconds}}{3{,}600}$$

This element converts the preceding into gallons of fuel.

It is the time to stop in hours.

Time to stop in seconds is computed approximately from the Braking Distance vs. Speed curve of the railroad by the step by step method as follows:

$$t_{60\text{-}50} = \frac{BD_{60} - BD_{50}}{55 \times 1.467} = \text{seconds}$$

$$t_{50\text{-}40} = \frac{BD_{50} - BD_{40}}{45 \times 1.467} = \text{seconds}$$

and so on for 40-30, 30-20, 20-10, and 10-0 speed intervals, the total time to stop being the sum of these parts.

Note.—In computing the extra fuel curves, A.A.R. Sig. Sec. 7066 through 7071, the time of a stop was computed by a more complex method involving the retarding forces of the brakes on the locomotive and the cars.

3,600 is the number of seconds per hour.

which may be written

Fuel in gallons consumed while braking

$= 0.000278 \times F.C._{NL} \times U \times T_b$

Fuel in gallons consumed while standing

= no load fuel consumption in gallons per hour per unit

This element represents the fuel rate per locomotive unit.

× number of units in the locomotive

This element converts the preceding into the fuel rate for the locomotive.

$$\times \frac{\text{standing time in minutes}}{60}$$

This element converts the preceding into gallons of fuel.

It is the standing time in hours.

The standing time in minutes is the time required to pump up the air, usually 3 to 6 minutes.

60 is the number of minutes per hour.

which may be written

Fuel in gallons consumed while standing

$= 0.0167 \times F.C._{NL} \times U \times T_s$

Fuel in gallons consumed while accelerating

= full load fuel consumption in gallons per hour per unit

This element represents the fuel rate per locomotive unit.

× number of units in the locomotive

This element converts the preceding into the fuel rate for the locomotive.

$$\times \frac{\text{time to accelerate to speed S in seconds}}{3{,}600}$$

This element converts the preceding into gallons of fuel.

It is the time to accelerate in hours.

The time T in seconds to accelerate to speed S is obtained from the speed-time data which are computed on the step by step differential speed basis described under steam power.

3,600 is the number of seconds per hour.

which may be written

Fuel in gallons consumed while accelerating

$= 0.000278 \times F.C._{FL} \times U \times T_a$

Fuel in gallons consumed in running through at speed S

= fuel consumption in gallons per hour per unit at running through speed ($F.C._S$)

This element represents the fuel rate per locomotive unit at the running through speed.

It is obtained from the chart "Fuel Consumption vs. Load," Fig. 5.

The load in per cent of full

$$= \frac{\text{train resistance } R_T \text{ at speed S}}{\text{tractive force T.F. at speed S}} \times 100$$

Of course, should the Fuel Rate vs. Load curve for the specific locomotive be available, that curve should be used in place of the curve shown in Fig. 5.

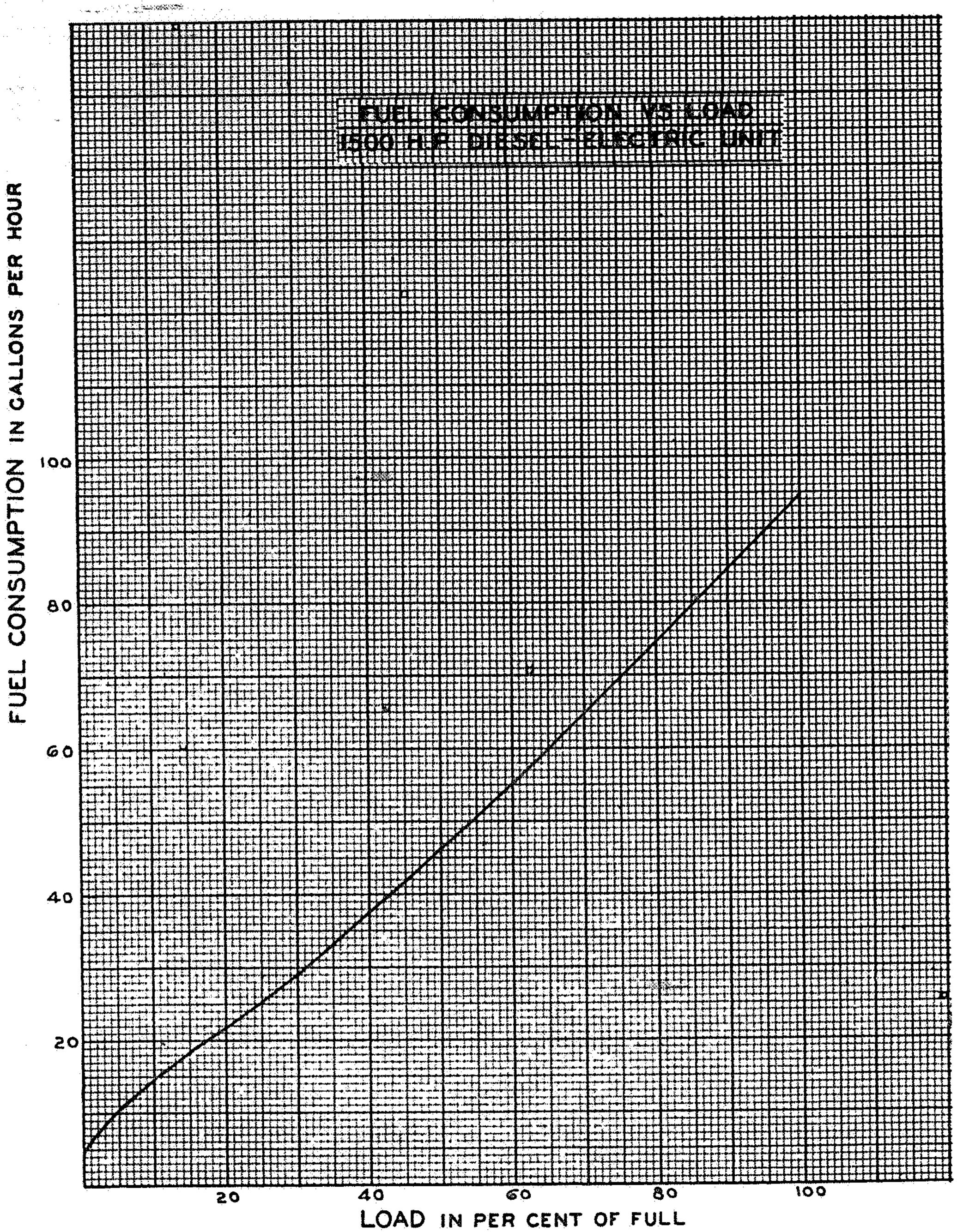

FUEL CONSUMPTION VS LOAD
1500 H.P. DIESEL-ELECTRIC UNIT
FUEL CONSUMPTION IN GALLONS PER HOUR
100
80
60
40
20
20
40
60
80
100
LOAD IN PER CENT OF FULL

Fig. 5.

$\times$ number of units in the locomotive

This element converts the preceding into the fuel rate for the locomotive at the running through speed.

$$\times \frac{\text{braking distance in feet} + \text{accelerating distance in feet}}{\text{running through speed S in miles per hour} \times 5{,}280}$$

This element converts the preceding into gallons of fuel.

It is the time in hours to run through.

The braking distance in feet is obtained from the Braking Distance vs. Speed curve of the railroad.

The acceleration distance is obtained from the speed-distance data which are computed on the step by step differential speed basis described under steam power. Obviously, there is no need to compute the work interval data required for steam power.

5,280 is the number of feet per mile.

which may be written

Fuel in gallons consumed in running through at speed S

$$= F.C._S \times U \times \frac{0.000189\,(D_b + D_a)}{S}$$

From the above, it is apparent that, with Diesel-electric locomotives, the solution is slightly different from that with steam locomotives in that

1. The stop is made with the throttle closed; thus, it is necessary to consider the fuel consumed during the braking portion of the stop cycle, as well as during the acceleration portion.
2. The fuel consumption is known in terms of gallons per hour vs. load; thus, it is necessary to determine the time interval of operation at each load.

While it is believed that the curves herein will cover practically all cases, there may be cases where it is desired to compute the cost for a specific train; therefore, a procedure is outlined whereby the various times may be determined for use in the above formulas.

Distance and Time vs. Speed

During the braking portion of the cycle,

the distance traversed in braking from any speed is, of course, obtained from the Braking Distance vs. Speed curve of the railroad, and

the time required to brake to a stop from any speed, if not available in chart form, may be computed approximately from the braking distance chart data by the step by step method as follows:

$$t_{60-50} = \frac{BD_{60} - BD_{50}}{55 \times 1.467} = \text{seconds}$$

$$t_{50-40} = \frac{BD_{50} - BD_{40}}{45 \times 1.467} = \text{seconds}$$

and so on for 40-30, 30-20, 20-10, and 10-0 speed intervals, the total time to stop being the sum of these parts.

Note.—In computing the extra fuel curves, A.A.R. Sig. Sec. 7066 through 7071, the time of a stop was computed by a more complex method involving the retarding forces of the brakes on the locomotive and the cars.

During the acceleration portion of the cycle, the distance traversed and the time consumed are computed on a step by step differential speed basis the same as described for steam power. Obviously, there is no need to compute the work interval data required for steam power.

Tractive Force vs. Speed

The Tractive Force vs. Speed curve for the specific Diesel-electric locomotive is generally obtainable from the superintendent of motive power.

Published information indicates that there is comparatively little difference between the locomotives of different manufacturers, and that

$$\text{tractive force} = \frac{308 \times \text{horsepower}}{\text{speed}} \qquad \text{(approx.)}$$

therefore, when the specific Tractive Force vs. Speed characteristic curve is not available, one of the curves herein may be used and the result will be sufficiently accurate. Bear in mind that the maximum continuous tractive force and the maximum permissible speed applying to the specific locomotive will limit the portion of the curve that may be used.

Curves have been included for 1,500 and 1,600 horsepower units, with published operating limits for certain gear ratios indicated, these limits being superseded by the known limits for a specific locomotive. See Figs. 6, 7 and 8.

COST OF STOPPING TRAINS

(Diesel Power Example)

Cost of fuel wasted making stop, in dollars

= (fuel in gallons consumed while braking

+ fuel in gallons consumed while standing

+ fuel in gallons consumed while accelerating

− fuel in gallons consumed in running through at speed)

× cost of fuel in dollars per gallon

where

Fuel in gallons consumed while braking

$= 0.000278 \times F.C._{NL} \times U \times T_b$

Fuel in gallons consumed while standing

$= 0.0167 \times F.C._{NL} \times U \times T_s$

Fuel in gallons consumed while accelerating

$= 0.000278 \times F.C._{FL} \times U \times T_a$

Fuel in gallons consumed in running through at speed

$$= F.C._s \times U \times \frac{0.000189\,(D_b + D_a)}{S}$$

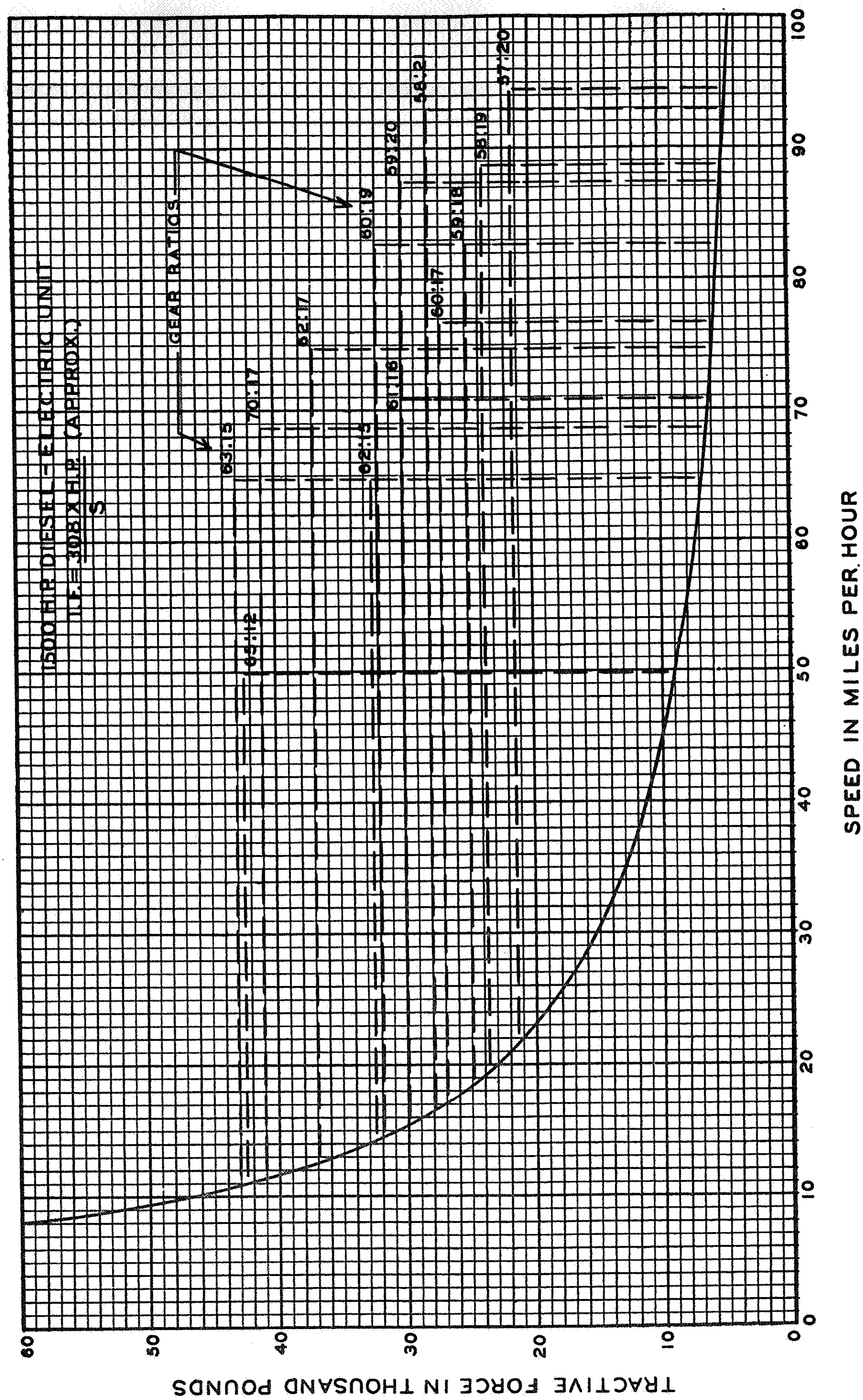

1500 H.P. DIESEL - ELECTRIC UNIT
T.F. = 308 X H.P. (APPROX.) / S
GEAR RATIOS
65:12
63:15
70:17
62:17
62:15
60:19
61:18
59:20
60:17
59:18
58:2
58:19
57:20
0
10
20
30
40
50
60
70
80
90
100
SPEED IN MILES PER HOUR
TRACTIVE FORCE IN THOUSAND POUNDS

Fig. 6.

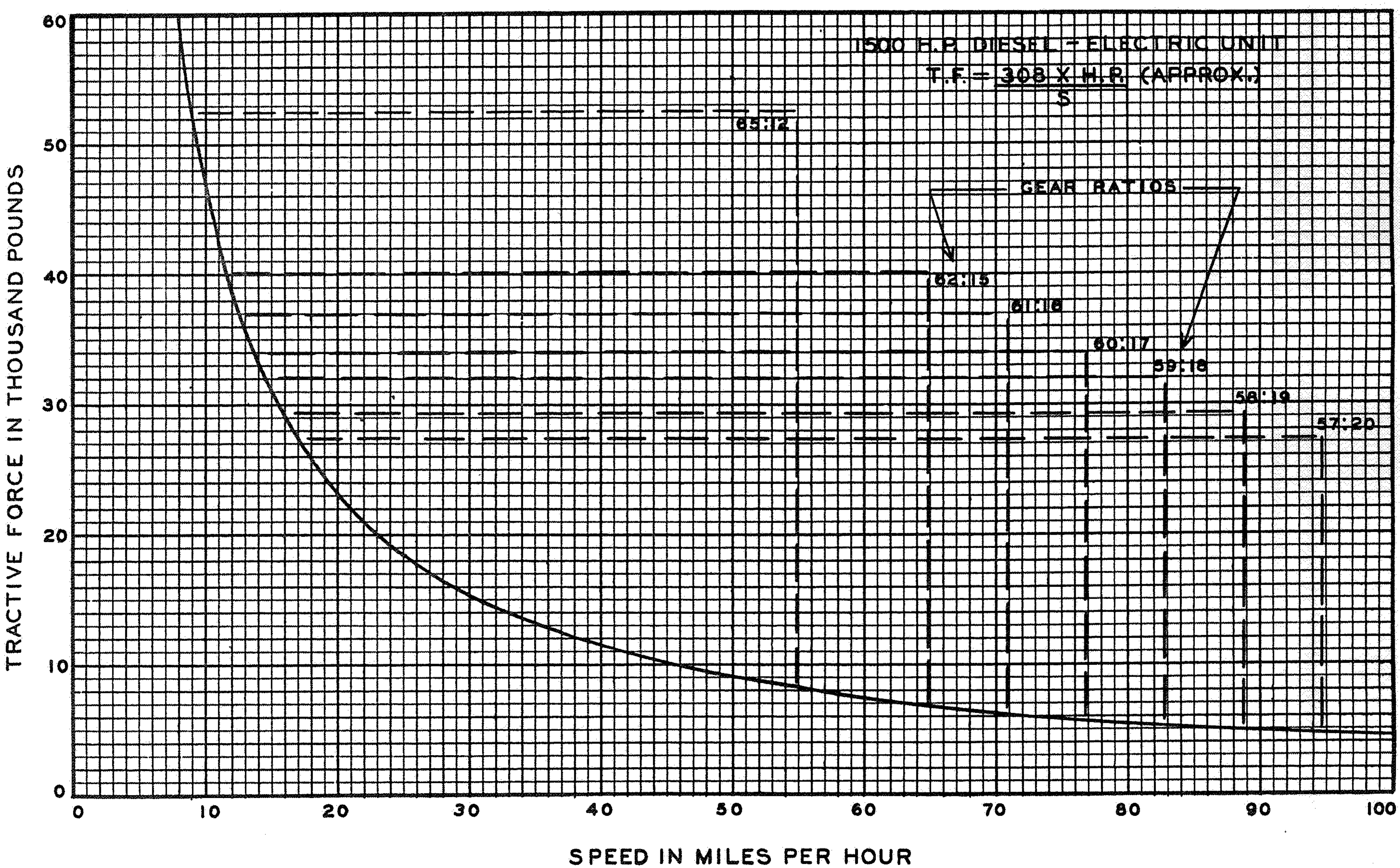

1500 H.P. DIESEL - ELECTRIC UNIT
T.F. = 308 X H.P. / S (APPROX.)
GEAR RATIOS
65:12
62:15
61:16
60:17
59:18
58:19
57:20
TRACTIVE FORCE IN THOUSAND POUNDS
0
10
20
30
40
50
60
0
10
20
30
40
50
60
70
80
90
100
SPEED IN MILES PER HOUR

Fig. 7.

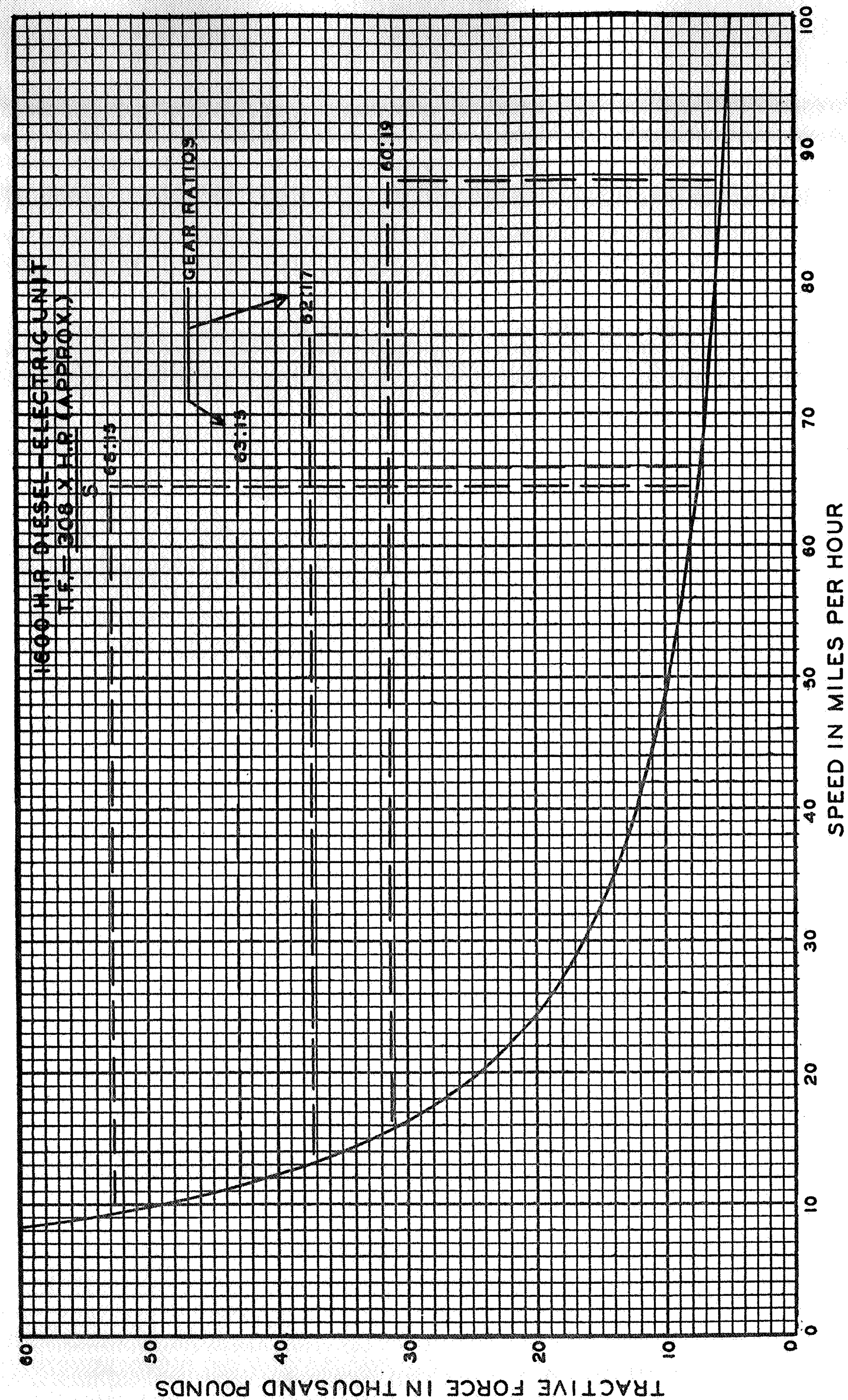

1600 H.P. DIESEL-ELECTRIC UNIT
T.F. = 308 X H.P. (APPROX.)
S
GEAR RATIOS
65:15
63:15
62:17
60:19
TRACTIVE FORCE IN THOUSAND POUNDS
0
10
20
30
40
50
60
SPEED IN MILES PER HOUR
0
10
20
30
40
50
60
70
80
90
100

Fig. 8.

Given

Locomotive—3 (U) 1,500 h.p. units

345 tons total weight

62:15 gear ratio

94.5 gallons per hour per unit full load fuel consumption ($F.C._{FL}$)

3.5 gallons per hour per unit no load fuel consumption ($F.C._{NL}$)

Train — 84 cars average

45 tons per car average (actual)

3,780 tons load

345 tons locomotive

4,100 tons total (W)

Braking distance—3,960 feet at 45 m.p.h. (D_b)

350 feet at 10 m.p.h. (D_b)

Track—level tangent

Cost of Diesel fuel oil—$0.10 per gallon.

STOP FROM 45 M.P.H.

Fuel in gallons consumed while braking

$= 0.000278 \times 3.5 \times 3 \times 138$

$= 0.4$

$$t_{45-40} = \frac{3,960 - 3,000}{42.5 \times 1.467} = \frac{960}{62} = 15 \text{ secs.}$$

$$t_{40-30} = \frac{3,000 - 1,470}{35 \times 1.467} = \frac{1,260}{51} = 25 \text{ secs.}$$

$$t_{30-20} = \frac{1,470 - 900}{25 \times 1.467} = \frac{840}{37} = 23 \text{ secs.}$$

$$t_{20-10} = \frac{900 - 350}{15 \times 1.467} = \frac{550}{22} = 25 \text{ secs.}$$

$$t_{10-0} = \frac{350 - 0}{5 \times 1.467} = \frac{350}{7} = 50 \text{ secs.}$$

$T_D = 15 + 25 + 23 + 25 + 50 = 138$ secs.

Fuel in gallons consumed while standing

$= 0.0167 \times 3.5 \times 3 \times 3$

$= 0.5$

Fuel in gallons consumed while accelerating

$= 0.000278 \times 94.5 \times 3 \times 1,266$

$= 99.7$

$P = T.F. - R_T$. $96W = 393,000$. $A = \frac{P}{393,000}$. $t = \frac{S_2 - S_1}{A}$.

$d = S_{av} \times 1.467 \times t$.

S_1 m.p.h.	S_2 m.p.h.	S_{av} m.p.h.	T.F.$_{1}$ lbs.	T.F.$_{3}$ lbs.	R_t lbs./ton	R_T lbs.	P lbs.	A m/h/s	t secs.	T_a secs.	d ft.	D_a ft.
0	5	2.5	35,750	107,250	4.0	16,400	90,850	0.2312	21.68	22	79.5	80
5	10	7.5	35,750	107,250	4.1	16,800	90,450	0.2302	21.72	44	238.6	319
10	14	12	35,750	107,250	4.4	18,000	89,250	0.2270	17.63	62	310.6	630
14	18	16	31,765	95,295	4.7	19,270	76,025	0.1934	20.68	83	486.0	1,116
18	22	20	25,410	76,230	5.0	20,500	55,730	0.1418	28.22	111	829.5	1,946
22	26	24	21,175	63,525	5.4	22,140	41,385	0.1053	38.00	149	1338	3,284
26	30	28	18,150	54,450	5.8	23,780	30,670	0.07805	51.20	200	2104	5,388
30	34	32	15,880	47,640	6.2	25,420	22,240	0.05660	70.60	271	3316	8,704
34	38	36	14,115	42,345	6.7	27,470	14,875	0.03786	105.6	377	5565	14,269
38	42	40	12,705	38,115	7.3	29,930	8,175	0.02080	192.3	569	11280	25,549
42	45	43.5	11,685	35,055	8.0	32,800	2,255	0.00574	696.5	1,266	44450	69,999

Fuel in gallons consumed in running through at 45 m.p.h.

$$= 94.5 \times 3 \times \frac{0.000189\,(3{,}960 + 70{,}000)}{45}$$

$= 94.5 \times 3 \times 0.3106$

$= 88.1$

At 45 m.p.h. the locomotive would be working at full load.

Cost of fuel wasted making stop from 45 m.p.h., in dollars

$= (0.4 + 0.5 + 99.7 - 88.1) \times 0.10$

$= \$1.25$

STOP FROM 10 M.P.H.

Fuel in gallons consumed while braking

$= 0.000278 \times 3.5 \times 3 \times 50$

$= 0.15$

Fuel in gallons consumed while standing

$= 0.0167 \times 3.5 \times 3 \times 1$

$= 0.18$

Fuel in gallons consumed while accelerating

$= 0.000278 \times 94.5 \times 3 \times 44$

$= 3.47$

Fuel in gallons consumed in running through at 10 m.p.h.

$$= 19.5 \times 3 \times \frac{0.000189\,(350 + 320)}{20}$$

$= 19.5 \times 3 \times 0.00634$

$= 0.37$

At 10 m.p.h. the locomotive would be working at 16.5 per cent load and the fuel consumption would be 19.5 gallons per hour.

Cost of fuel wasted making stop from 10 m.p.h., in dollars

$= (0.15 + 0.18 + 3.47 - 0.37) \times 0.10$

$= \$0.34$

COST OF BRAKE SHOE WEAR IN MAKING STOP

The foot-pounds of work stored (kinetic energy) in any train at any speed, if not expended doing work in moving the train after the throttle is closed, must be dissipated by the brakes, which entails brake shoe wear and a cost.

Since it has been previously assumed that a train stop is usually made with open throttle, the brakes must not only dissipate the kinetic energy but also work produced by the locomotive while making the stop; however, in order to simplify the problem and evolve a conservative cost, the following cost is based upon the dissipation of the kinetic energy only.

It has been determined by laboratory tests at the University of Illinois (Bulletin No. 257, page 80, Table 24) that the wear of brake shoes of the type generally used in train service is 0.346 pound when applied to chilled car wheels and 0.53 pound when applied to steel wheels per hundred million foot-pounds of work absorbed, or dissipated, from 30 miles per hour.

Assuming a ratio of 50-50 for chilled and steel car wheels, the average wear based upon the laboratory tests would be 0.438 pound per hundred million foot-pounds of work dissipated when the stop is made from 30 miles per hour. In actual service, sand and ballast dust will increase the wear at least 10 per cent to say 0.5 pound per hundred million foot-pounds of work.

The average weight of a new brake shoe is 22.5 pounds, and the average weight of a scrap brake shoe is 8.5 pounds, which gives an average weight of usable metal of 14 pounds.

The A.A.R. Interchange Rules, governing charges for repairs to foreign line cars, sets the cost of a brake shoe including the cost of labor to apply it at \$1.81 as of January 1953; hence, the cost of brake shoe wear metal is \$1.81 ÷ 14 = \$0.1293 per pound.

It was previously shown that the kinetic energy equals 70 WS^2, which for a 6,000-ton train running at 30 miles per hour would be 3.78 hundred million foot-pounds.

Thus the cost of brake shoe wear for such a train stop would be $0.5 \times 3.78 \times 0.1293 = \$0.24$.

COST OF SLOWING DOWN

The basic approach to the cost of stopping trains may be applied to determine the cost of a slow-down due to a speed restriction (turnout, crossing, municipality, curve, etc.), i.e., in that case where the train is running at speed, decelerates because of the restriction, and then accelerates to the original running speed.

Technically, the cost of the slow-down is not so much in the deceleration of the train which involves brake shoe wear as in the acceleration of the train which involves the restoration of the potential or kinetic energy the same as when the train is accelerated to speed after a stop.

The cycle when slowing down is different from the cycle when making a stop, in that it is probable that the deceleration in the majority of slow-down cases is accomplished by closing the throttle and permitting the train resistance to absorb the energy and thus reduce the speed.

Thus, the work performed by the locomotive in traversing the deceleration distance would be less in the case of deceleration as compared with running through that distance at speed.

For all practical purposes, sufficiently accurate results would be obtained by subtracting the work wasted making stcp from the slow-down speed from the work wasted making stop from the running through speed, and disregarding the difference in work required to maintain the slow-down speed for the distance the speed restriction is effective as compared with the work required to maintain the running through speed for the same distance.

COST OF REGAINING LOST TIME AFTER STOP

In general, in order to make the schedule (either published or implied), it is necessary for the average weight train to run at the maximum speed attainable by the locomotive on the profile, limited of course by speed restrictions on certain sections where higher speeds could be attained.

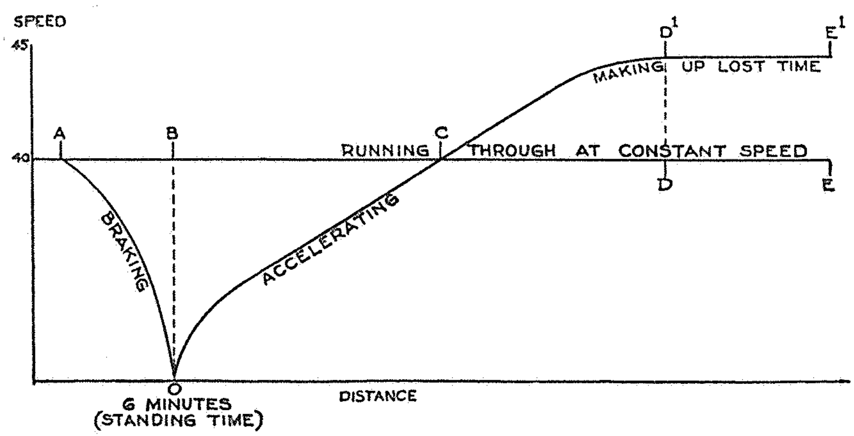
The previous costs involved in stopping trains are intended primarily for use in connection with the effect on an established schedule.

The stop is to be either added to or deducted from the existing schedule; consequently, the cost of same should be balanced against either the benefits derived or the penalty incurred.

In a specific instance of stop, where regaining lost time is feasible and it is desired to complete the economic study, the cost of regaining lost time may be calculated.

To obtain the distance necessary to travel at a higher than schedule speed, the tabulation (folded sheet following this page) gives the make-up time speeds (in increments of 1 mile per hour from 25 to 100 miles per hour) and the distance (in miles) required to be run at the make-up time speed in order to regain 1 minute of lost time.

The following speed-distance diagram illustrates the stop cycle and the typical example for stopping a 6,450-ton gross weight train of 80-ton cars hauled by a 2-10-4 (245 pounds per square inch gage, 250 degrees superheat, 121 square feet grate area, using coal with 13,500 B.T.U.'s per pound at $3.21 per ton and water at 12 cents per 1,000 gallons) locomotive on level tangent track from 40 miles per hour, standing 6 minutes, and regaining the lost time by running at 45 miles per hour until the lost time is made up, as against running through at the normal speed of 40 miles per hour without stopping.



Braking AO	= 112.5 secs.	Running through AB =	71.7 secs.
Standing at O	= 360.0 secs.		
Accelerating OC	= 575.4 secs.	Running through BC =	367.0 secs.
	1,047.9 seconds less		438.7 secs.

= 609.2 seconds or 10.153 minutes total lost time

DISTANCE IN MILES REQUIRED TO TRAVEL TO MAKE UP 1 MINUTE AT MAKE UP TIME SPEED.

1	2	3	4	5	6	7	8	9	10
S'	S = 25 M.P.H.			S = 30 M.P.H.			S = 35 M.P.H.		
MAKE UP SPEED	SS'	60(S'-S)	D = COL. 2 / COL. 3	SS'	60(S'-S)	D = COL. 5 / COL. 6	SS'	60(S'-S)	D = COL. 8 / COL. 9
25	625	0	INFIN.						
26	650	60	10.833						
27	675	120	5.625						
28	700	180	3.888						
29	725	240	3.021						
30	750	300	2.500	900	0	INFIN.			
31	775	360	2.153	930	60	15.500			
32	800	420	1.905	960	120	8.000			
33	825	480	1.719	990	180	5.500			
34	850	540	1.574	1020	240	4.250			
35	875	600	1.458	1050	300	3.500	1225	0	INFIN.
36	900	660	1.364	1080	360	3.000	1260	60	21.000
37	925	720	1.285	1110	420	2.643	1295	120	10.792
38	950	780	1.218	1140	480	2.375	1330	180	7.389
39	975	840	1.161	1170	540	2.167	1365	240	5.6875
40	1000	900	1.111	1200	600	2.000	1400	300	4.667
41	1025	960	1.068	1230	660	1.864	1435	360	3.986
42	1050	1020	1.029	1260	720	1.750	1470	420	3.500
43	1075	1080	.9953	1290	780	1.654	1505	480	3.135
44	1100	1140	.9649	1320	840	1.571	1540	540	2.852
45	1125	1200	.9375	1350	900	1.500	1575	600	2.625
46	1150	1260	.9127	1380	960	1.4375	1610	660	2.439
47	1175	1320	.8902	1410	1020	1.382	1645	720	2.285
48	1200	1380	.8696	1440	1080	1.333	1680	780	2.154
49	1225	1440	.8507	1470	1140	1.289	1715	840	2.042
50	1250	1500	.8333	1500	1200	1.250	1750	900	1.944
51	1275	1560	.8173	1530	1260	1.214	1785	960	1.859
52	1300	1620	.8025	1560	1320	1.182	1820	1020	1.784
53	1325	1680	.7887	1590	1380	1.152	1855	1080	1.718
54	1350	1740	.7759	1620	1440	1.125	1890	1140	1.658
55	1375	1800	.7639	1650	1500	1.100	1925	1200	1.604
56	1400	1860	.7527	1680	1560	1.077	1960	1260	1.555
57	1425	1920	.7422	1710	1620	1.055	1995	1320	1.511
58	1450	1980	.7323	1740	1680	1.036	2030	1380	1.471
59	1475	2040	.7230	1770	1740	1.017	2065	1440	1.434
60	1500	2100	.7143	1800	1800	1.000	2100	1500	1.400
61	1525	2160	.7060	1830	1860	.9839	2135	1560	1.369
62	1550	2220	.6982	1860	1920	.96875	2170	1620	1.339
63	1575	2280	.6908	1890	1980	.9545	2205	1680	1.312
64	1600	2340	.6838	1920	2040	.9412	2240	1740	1.287
65	1625	2400	.6771	1950	2100	.9286	2275	1800	1.264
66	1650	2460	.6707	1980	2160	.9167	2310	1860	1.242
67	1675	2520	.6647	2010	2220	.9054	2345	1920	1.221
68	1700	2580	.6589	2040	2280	.8947	2380	1980	1.202
69	1725	2640	.6534	2070	2340	.8846	2415	2040	1.184
70	1750	2700	.6481	2100	2400	.8750	2450	2100	1.167
71	1775	2760	.6431	2130	2460	.8658	2485	2160	1.150
72	1800	2820	.6383	2160	2520	.8571	2520	2220	1.135
73	1825	2880	.6337	2190	2580	.8488	2555	2280	1.121
74	1850	2940	.6293	2220	2640	.8409	2590	2340	1.107
75	1875	3000	.6250	2250	2700	.8333	2625	2400	1.09375
76	1900	3060	.6209	2280	2760	.8261	2660	2460	1.081
77	1925	3120	.6170	2310	2820	.8191	2695	2520	1.069
78	1950	3180	.6132	2340	2880	.8125	2730	2580	1.058
79	1975	3240	.6096	2370	2940	.8061	2765	2640	1.047
80	2000	3300	.6061	2400	3000	.8000	2800	2700	1.037
81	2025	3360	.6027	2430	3060	.7941	2835	2760	1.027
82	2050	3420	.5994	2460	3120	.7885	2870	2820	1.018
83	2075	3480	.5963	2490	3180	.7830	2905	2880	1.009
84	2100	3540	.5932	2520	3240	.7777	2940	2940	1.000
85	2125	3600	.5903	2550	3300	.7727	2975	3000	.9917
86	2150	3660	.5870	2580	3360	.7679	3010	3060	.9837
87	2175	3720	.5847	2610	3420	.7632	3045	3120	.976
88	2200	3780	.5820	2640	3480	.7586	3080	3180	.9686
89	2225	3840	.5794	2670	3540	.7542	3115	3240	.9614
90	2250	3900	.5769	2700	3600	.7500	3150	3300	.9545
91	2275	3960	.5745	2730	3660	.7459	3185	3360	.9479
92	2300	4020	.5721	2760	3720	.7419	3220	3420	.9415
93	2325	4080	.5699	2790	3780	.7381	3255	3480	.9353
94	2350	4140	.5676	2820	3840	.7344	3290	3540	.9294
95	2375	4200	.5655	2850	3900	.7308	3325	3600	.9236
96	2400	4260	.5634	2880	3960	.7273	3360	3660	.9180
97	2425	4320	.5614	2910	4020	.7239	3395	3720	.9126
98	2450	4380	.5594	2940	4080	.7206	3430	3780	.9074
99	2475	4440	.5574	2970	4140	.7174	3465	3840	.9023
100	2500	4500	.5555	3000	4200	.7143	3500	3900	.8974

1	11	12	13	14	15	16	17	18	19
S'	S = 40 M.P.H.			S = 45 M.P.H.			S = 50 M.P.H.		
MAKE UP SPEED	SS'	60(S'-S)	D = COL. 11 / COL. 12	SS'	60(S'-S)	D = COL. 14 / COL. 15	SS'	60(S'-S)	D = COL. 17 / COL. 18
40	1600	0	INFIN.						
41	1640	60	27.333						
42	1680	120	14.000						
43	1720	180	9.555						
44	1760	240	7.333						
45	1800	300	6.000	2025	0	INFIN.			
46	1840	360	5.111	2070	60	34.500			
47	1880	420	4.476	2115	120	17.625			
48	1920	480	4.000	2160	180	12.000			
49	1960	540	3.630	2205	240	9.1875			
50	2000	600	3.333	2250	300	7.500	2500	0	INFIN.
51	2040	660	3.091	2295	360	6.375	2550	60	42.500
52	2080	720	2.889	2340	420	5.571	2600	120	21.750
53	2120	780	2.718	2385	480	4.969	2650	180	14.720
54	2160	840	2.571	2430	540	4.500	2700	240	11.250
55	2200	900	2.444	2475	600	4.125	2750	300	9.167
56	2240	960	2.333	2520	660	3.818	2800	360	7.777
57	2280	1020	2.235	2565	720	3.5625	2850	420	6.786
58	2320	1080	2.148	2610	780	3.346	2900	480	6.042
59	2360	1140	2.070	2655	840	3.160	2950	540	5.463
60	2400	1200	2.000	2700	900	3.000	3000	600	5.000
61	2440	1260	1.9365	2745	960	2.859	3050	660	4.621
62	2480	1320	1.879	2790	1020	2.735	3100	720	4.306
63	2520	1380	1.826	2835	1080	2.625	3150	780	4.038
64	2560	1440	1.777	2880	1140	2.526	3200	840	3.809
65	2600	1500	1.733	2925	1200	2.4375	3250	900	3.611
66	2640	1560	1.692	2970	1260	2.357	3300	960	3.4375
67	2680	1620	1.654	3015	1320	2.284	3350	1020	3.284
68	2720	1680	1.619	3060	1380	2.217	3400	1080	3.148
69	2760	1740	1.586	3105	1440	2.156	3450	1140	3.026
70	2800	1800	1.555	3150	1500	2.100	3500	1200	2.9167
71	2840	1860	1.526	3195	1560	2.048	3550	1260	2.817
72	2880	1920	1.500	3240	1620	2.000	3600	1320	2.727
73	2920	1980	1.475	3285	1680	1.955	3650	1380	2.645
74	2960	2040	1.451	3330	1740	1.914	3700	1440	2.569
75	3000	2100	1.429	3375	1800	1.875	3750	1500	2.500
76	3040	2160	1.407	3420	1860	1.839	3800	1560	2.436
77	3080	2220	1.387	3465	1920	1.805	3850	1620	2.376
78	3120	2280	1.368	3510	1980	1.773	3900	1680	2.321
79	3160	2340	1.350	3555	2040	1.743	3950	1740	2.270
80	3200	2400	1.333	3600	2100	1.714	4000	1800	2.222
81	3240	2460	1.317	3645	2160	1.6875	4050	1860	2.177
82	3280	2520	1.302	3690	2220	1.662	4100	1920	2.135
83	3320	2580	1.287	3735	2280	1.619	4150	1980	2.096
84	3360	2640	1.273	3780	2340	1.602	4200	2040	2.059
85	3400	2700	1.259	3825	2400	1.594	4250	2100	2.024
86	3440	2760	1.246	3870	2460	1.573	4300	2160	1.991
87	3480	2820	1.234	3915	2520	1.553	4350	2220	1.959
88	3520	2880	1.222	3960	2580	1.535	4400	2280	1.930
89	3560	2940	1.211	4005	2640	1.517	4450	2340	1.902
90	3600	3000	1.200	4050	2700	1.500	4500	2400	1.875
91	3640	3060	1.189	4095	2760	1.484	4550	2460	1.850
92	3680	3120	1.179	4140	2820	1.468	4600	2520	1.825
93	3720	3180	1.170	4185	2880	1.453	4650	2580	1.802
94	3760	3240	1.160	4230	2940	1.439	4700	2640	1.780
95	3800	3300	1.151	4275	3000	1.425	4750	2700	1.759
96	3840	3360	1.143	4320	3060	1.412	4800	2760	1.739
97	3880	3420	1.134	4365	3120	1.399	4850	2820	1.720
98	3920	3480	1.126	4410	3180	1.387	4900	2880	1.701
99	3960	3540	1.119	4455	3240	1.375	4950	2940	1.684
100	4000	3600	1.111	4500	3300	1.364	5000	3000	1.667

1	20	21	22	23	24	25	26	27	28
S'	S = 55 M.P.H.			S = 60 M.P.H.			S = 65 M.P.H.		
MAKE UP SPEED	SS'	60(S'-S)	D = COL. 20 / COL. 21	SS'	60(S'-S)	D = COL. 23 / COL. 24	SS'	60(S'-S)	D = COL. 26 / COL. 27
55	3025	0	INFIN.						
56	3080	60	51.333						
57	3185	120	26.125						
58	3190	180	17.722						
59	3245	240	13.521						
60	3300	300	11.000	3600	0	INFIN.			
61	3355	360	9.319	3660	60	61.000			
62	3410	420	8.119	3720	120	31.000			
63	3465	480	7.219	3780	180	21.000			
64	3520	540	6.518	3840	240	16.000			
65	3576	600	5.958	3900	300	13.000	4225	0	INFIN.
66	3630	660	5.500	3960	360	11.000	4290	60	71.600
67	3685	720	5.118	4020	420	9.571	4355	120	36.292
68	3740	780	4.795	4080	480	8.500	4420	180	24.556
69	3795	840	4.518	4140	540	7.667	4485	240	18.6875
70	3850	900	4.277	4200	600	7.000	4550	300	15.167
71	3905	960	4.068	4260	660	6.455	4615	360	12.819
72	3960	1020	3.882	4320	720	6.000	4680	420	11.143
73	4015	1080	3.718	4380	780	5.615	4745	480	9.885
74	4070	1140	3.570	4440	840	5.286	4810	540	8.907
75	4125	1200	3.437	4500	900	5.000	4875	600	8.125
76	4180	1260	3.317	4560	960	4.750	4940	660	7.485
77	4235	1320	3.208	4620	1020	4.529	5005	720	6.951
78	4290	1380	3.109	4680	1080	4.333	5070	780	6.500
79	4345	1440	3.017	4740	1140	4.158	5135	840	6.113
80	4400	1500	2.933	4800	1200	4.000	5200	900	5.778
81	4455	1560	2.856	4860	1260	3.857	5265	960	5.484
82	4510	1620	2.784	4920	1320	3.727	5330	1020	5.225
83	4565	1680	2.717	4980	1380	3.609	5395	1080	4.995
84	4620	1740	2.655	5040	1440	3.500	5460	1140	4.789
85	4675	1800	2.597	5100	1500	3.400	5525	1200	4.604
86	4730	1860	2.543	5160	1560	3.308	5590	1260	4.436
87	4785	1920	2.492	5220	1620	3.222	5655	1320	4.284
88	4840	1980	2.444	5280	1680	3.143	5720	1380	4.145
89	4895	2040	2.399	5340	1740	3.069	5785	1440	4.017
90	4950	2100	2.357	5400	1800	3.000	5850	1500	3.900
91	5005	2160	2.317	5460	1860	2.935	5915	1560	3.792
92	5060	2220	2.279	5520	1920	2.875	5980	1620	3.691
93	5115	2280	2.243	5580	1980	2.818	6045	1680	3.598
94	5170	2340	2.209	5640	2040	2.765	6110	1740	3.511
95	5225	2400	2.177	5700	2100	2.714	6175	1800	3.430
96	5280	2460	2.146	5760	2160	2.667	6240	1860	3.355
97	5335	2520	2.117	5820	2220	2.622	6305	1920	3.284
98	5390	2580	2.089	5880	2280	2.579	6370	1980	3.217
99	5445	2640	2.0625	5940	2340	2.538	6435	2040	3.154
100	5500	2700	2.037	6000	2400	2.500	6500	2100	3.095

— FORMULA FOR CALCULATING DISTANCE NECESSARY TO TRAVEL AT A HIGHER THAN SCHEDULED SPEED — TO MAKE UP A GIVEN AMOUNT OF LOST TIME.

WHEN $D = SH$ = MILES TRAVELED.
AND H = HOURS TIME
LET S = SPEED M.P.H.
M = MINUTES TIME.
THEN $H = \frac{M}{60}$
AND $D = \frac{SM}{60}$
OR $M = \frac{60D}{S}$

LET T = TIME IN MINUTES TO BE MADE UP.
S = M.P.H. SCHEDULED SPEED.
S' = M.P.H. "MAKE UP TIME" SPEED.
D = DISTANCE IN MILES.
M = TIME IN MINUTES TO TRAVEL "D" MILES AT SCHEDULE SPEED.
M' = TIME IN MINUTES TO TRAVEL "D" MILES AT MAKE UP TIME SPEED.

THEN $M' = \frac{60D}{S'}$

& $M = \frac{60D}{S}$

$M - M' = T = \frac{60D}{S} - \frac{60D}{S'}$

$TSS' = 60DS' - 60DS$

$60D(S' - S) = TSS'$

$D = \frac{TSS'}{60(S' - S)}$

BY ASSIGNING VALUES TO T, S, & S' VARIOUS VALUES OF "D" CAN BE CALCULATED AND CURVES PLOTTED.

BY ASSIGNING THE VALUE OF 1 TO "T" THE CALCULATIONS AND CURVES WILL GIVE THE DISTANCE REQUIRED TO MAKE UP 1 MINUTE OF TIME AND FOR 10 MINUTES THE DISTANCE WOULD BE 10 TIMES THE CALCULATED OR CURVE VALUE READING.

IN CALCULATIONS HEREWITH TABULATED THE SCHEDULED SPEEDS RANGE FROM 25 TO 65 M.P.H. IN STEPS OF 5 M.P.H. FOR MAKE-UP TIME SPEEDS IN 1 M.P.H. INCREMENTS UP TO 100 M.P.H.

$D = \frac{SS'}{60(S' - S)}$ = DISTANCE MILES TO MAKE-UP 1 MIN. TIME.

A.A.R. SIGNAL SECTION.
COMMITTEE I.
TABULATION OF DISTANCE IN MILES NECESSARY TO TRAVEL AT HIGHER THAN SCHEDULED SPEED TO MAKE UP 1 MINUTE LOST TIME.

The total time lost by stopping is the difference between running "AOC" with stop of 6 minutes standing time at "O," and running "ABC" without stopping.

Part of this total time lost is regained during the acceleration from 40 miles per hour normal speed to 45 miles per hour make-up time speed between points C and D^1 at the average speed of 42.5 miles per hour, and by referring to the tabulation of distances at 42.5 miles per hour, it is found that 11.5 miles is the distance required to make up 1 minute.

By the step by step method of computing the speed-distance data, it is found that the distance required to accelerate to 40 miles per hour is 9,400 feet or 1.78 miles, and the distance required to accelerate to 45 miles per hour is 18,800 feet or 3.56 miles, for a distance of 1.78 miles traveled at an average speed of 42.5 miles per hour. Therefore, $\frac{1.78}{11.5} = 0.155$ minute or 9.3 seconds time would be made up at a speed of 42.5 miles per hour, and this subtracted from 609.2 seconds = 599.9 seconds or 10 minutes remaining of the lost time to be regained running at 45 miles per hour between points D^1 and E^1.

By further reference to the tabulation of distances, at normal speed of 40 m.p.h. and make-up time speed of 45 m.p.h., 6 miles is determined as the distance required to make up 1 minute. Then, 6 miles × 10 minutes lost time = 60 miles, which is the distance required to be run at 45 m.p.h. to regain the remaining lost time.

With time and distance determined, the work wasted in h.p. hours may be calculated, and the cost of additional fuel and water involved account of stop, standing 6 minutes, and making up lost time may be determined as follows:

Work wasted accelerating to 45 m.p.h. = 345 h.p. hours.
(From chart A.A.R. Sig. Sec. 7062.)

Additional work required to haul train at 45 m.p.h. in place of 40 m.p.h.

= 6.4 lbs. per ton train resistance at 45 m.p.h. (from table)
5.6 lbs. per ton train resistance at 40 m.p.h. (from table)
0.8 lb. per ton additional train resistance

× 6,450 tons gross weight of train

× 316,800 feet traveled at 45 m.p.h. (60 miles)

÷ 1,980,000 foot-pounds per h.p. hour

= 826 h.p. hours

Total work wasted = 345 + 826 = 1,171 h.p. hours.

Cost of fuel wasted in stopping and regaining lost time by running at 45 m.p.h., in dollars

= 0.00085

× 1,171 (work wasted)

× 18 (steam factor from table)

× 1345.5 (heat content from table)

× 3.21 ($ per ton of coal)

÷ 13,500 (BTU's per pound of coal)

= $5.74 (1-a)

Cost of fuel consumed while standing, in dollars

$$
\begin{aligned}
&= 0.000125 \\
&\times 121 \quad \text{(square feet grate area)} \\
&\times 6 \quad \text{(minutes standing time)} \\
&\times 3.21 \quad \text{(\$ per ton of coal)} \\
&= \$0.29 \qquad \text{(2-a)}
\end{aligned}
$$

Cost of water wasted, in dollars

$$
\begin{aligned}
&= 0.00000133 \\
&\times 1{,}171 \quad \text{(work wasted)} \\
&\times 18 \quad \text{(steam factor as above)} \\
&\times 12 \quad \text{(cents per 1000 gallons)} \\
&= \$0.34 \qquad \text{(3)}
\end{aligned}
$$

Total cost of fuel and water wasted making stop from 40 m.p.h. and regaining lost time by running at 45 m.p.h.

$$
\begin{aligned}
&= \$5.74 \quad \text{(1-a)} \\
&+ \ 0.29 \quad \text{(2-a)} \\
&+ \ \underline{0.34} \quad \text{(3)} \\
&\ \ \ \$6.37
\end{aligned}
$$

Should it be desired to compute the ***additional*** cost of regaining lost time by running at higher than normal speed, it is only necessary to compute the cost of stopping the train from normal speed and subtract that cost from the above.

OTHER COSTS INVOLVED IN STOPPING TRAINS

In addition to the preceding costs, there are other items such as the following:

1. Wear on rails and track
2. Wear on wheels
3. Wear and tear on rolling stock
4. Locomotive maintenance and lubrication
5. Damage to lading
6. Commercial value of delay in delivery
7. Freight train delay hour

The first four of these are generally negligible.

The item of damage to lading for each common carrier amounts to a considerable sum annually. Whether this is chargeable either to the manner in which the train is operated or against improper stowage is debatable, but undoubtedly damage occurs in stopping and starting, and an estimate of the cost of damage chargeable to a stop may be made on the basis of monthly damage estimated to have occurred at stops divided by the total number of stops per month.

The item of commercial value of delay in delivery is indeterminate as a generality; however, if an unexpected stop results in a perishable shipment missing the market and spoiling, the cost would be equal to the claim, and the value would depend upon any accompanying loss of shipper good will and future traffic.

In a complete and comprehensive study, the item of freight train delay hour would be covered as previously described.

MATERIALS AND SUPPLIES

Change

FUEL

Aside from the fuel included in train time and train stops, it is possible, in certain territories where grades are an operating problem, to save fuel because the proposed operating method would permit the trains to approach the grade at higher speeds; whereupon, a greater part of the energy required to lift the train over the grade would be kinetic energy. Such a case would occur on single track where there is a siding in a sag—in the before method of operation it would be usual for the inferior train to get into the clear on the siding and it would not be able to make a run for the hill, whereas in the after method of operation, say centralized traffic control, the dispatcher could manipulate the signals in such a manner as to hold the heavier of the trains on the single track on the down grade until the lighter of the trains was into the clear on the siding and then release the heavier train which would thus have a run (at least the length of the siding) for the hill.

The probable fuel saving in such a case would have to be estimated and based upon the experience and judgment of the superintendent of motive power.

OTHER

The saving resulting from a reduction in materials and supplies may be that required to maintain and operate block offices and other buildings not required with the proposed system, or it may be that required to maintain and operate a signal system which will be replaced by the proposed system, or it may be that required to maintain switch lamps which will be replaced or eliminated by the proposed system.

Value

FUEL

Obviously, the value of the fuel saved would depend upon the costs of the particular railroad in that particular territory.

OTHER

The value of the material and supplies depends upon what is involved in the specific case, and should be obtained from the records of the railroad.

TAXES

Change

CORPORATE

Property.

The method of levying taxes on railroad properties varies widely, and whether the proposed operating method will result in either a reduction or an increase in taxes can best be answered by the tax expert of the railroad on each specific case.

In some localities, changing the class of track from main to siding, removing main track, and removing side track would result in a saving.

Therefore, in order that nothing is overlooked, a tabulation of the proposed track changes as indicated on the track plan should be submitted to the tax expert for his appraisal.

Income.

Where the installation of a signaling system results in the retirement of existing facilities and a net reduction in the capital account, the amount of the net reduction is charged to current operating expenses, which, of course, reduces the net income.

There are times when this reduction may result in a reduction in income taxes. While it is difficult to compute the exact amount, an endeavor should be made to do so, and failing this, mention should be made in order that this non-recurring item is not lost sight of in the complete presentation.

PAYROLL

Since the taxes for the Federal Railroad Retirement Plan and the contributions to Unemployment Plans and Insurance Plans are usually a percentage of the dollar amount of the payroll, these expenses should be included directly in the payroll computations.

Value

CORPORATE

Property.

The taxes vary widely, and the tax expert of the railroad should be consulted for the rates applicable for the specific study.

Income.

The tax rates vary widely, and the tax expert of the railroad should be consulted for the rates applicable for the specific study.

PAYROLL

The rate for payroll taxes is regulated by Federal law and prescribed to change from time to time, in which event it will, of course, be necessary to change the rate accordingly. As of January 1, 1952, the rate for Railroad Retirement was 6.25 per cent on all compensation up to $300 per month, and the rate for Unemployment Insurance was 0.5 per cent on all compensation up to $300 per month. The rate for any state payroll taxes may be obtained from the time clerk.

MAINTENANCE

Change

TRACK

When the proposed operating method involves the removal of main or side track, and the removal of switches, there is an attendant reduction possible in the maintenance expense.

Likewise, when main track is converted to side track, a lesser reduction is usually possible.

Where either-direction operation is instituted on a main track, some maintenance men consider the maintenance expense to be reduced because of the reduction in creepage.

Where two main tracks are converted to one main track with either-direction running, some maintenance men consider the maintenance to be less even though the remaining track is subjected to greater usage. On the other hand, other maintenance men consider that the greater usage results in an increase in the maintenance expense.

In view of the above, it is obvious that the changes in the track arrangement should be discussed with the maintenance-of-way engineers in order to ascertain the change in the maintenance expense.

SIGNAL

Where there was no signal system before the change, it is obvious that there would be a new item of signal maintenance expense.

Where additional signaling is installed, the change in signal maintenance expense may be computed on either the A.A.R. signal unit basis or the established basis of the railroad signal department.

MOTIVE POWER

Where the locomotive time saving as determined from the graphic train charts is sufficient to permit a reduction in the locomotive pool, a reduction should be possible in the locomotive maintenance expense. Where a part of a locomotive only is saved, a reduction in this expense might be possible.

This saving in maintenance may be evaluated either on a statistical basis or as determined by the motive power department.

OTHER

Additional savings in maintenance expenses may be possible due to the elimination of switch lamps, coal and water stations, block offices, electric power stations, changing from one type of electric power to another type, etc.

Value

TRACK

The value for the maintenance expense of any track item may generally be obtained from the railroad engineering department.

SIGNAL

The cost of maintenance and operation varies, depending upon local conditions on each railroad. The cost may be lower where additional signal maintenance labor is not involved and may vary from 1 to 4 per cent of the total cost of the new signaling. Where possible, the costs should be obtained from the records of the railroad signal department.

MOTIVE POWER

The cost of maintenance varies, depending upon local conditions on each railroad. Where possible, the costs should be obtained from the records of the railroad.

OTHER

The cost of maintenance varies for each item eliminated and local conditions on each railroad. Where possible, the costs should be obtained from the records of the railroad.

ENERGY

Change

The energy required to operate the signaling system may be included either in the operating expense or as a separate item, the former being the usual method.

The change in the energy requirements may be based either on actual records for similar signal locations or on load computations for the circuits.

Value

The cost of energy depends upon the type, source, and local conditions upon each railroad. Where possible, the costs should be obtained from the records of the railroad.

CAR TIME—CAR SAVING

Change

This information is determined from the graphic train charts, for when a train is redispatched, the time saving for the train in minutes multiplied by the number of cars in the train equals the car minutes saved. The total for the test days divided by the number of test days gives the average car minutes per day, which is then divided by 1,440 minutes per day to give the car days per day, which is then multiplied by 365 days per year to give the car days per year.

Another method is to multiply the freight train hours saved per day by the average number of cars per train to give the car hours per day, which is multiplied by 365 days per year to give the car hours per year, which is divided by 24 hours per day to give the car days per year.

Value

The value of a car day saved is the interest and depreciation on the investment and maintenance. This is true regardless of whether the car day saved is for either a foreign or home owned car.

The statistical value of a car day saved is usually taken as the per diem charge, because the per diem charge is intended to include the interest and depreciation on the investment and maintenance.

As of August 1, 1953, the per diem charge was $2.40.

When this value is applied to both foreign and home owned car days saved, which is usually the easiest method because it is not necessary to segregate the cars of the consists, a credit should not be taken under per diem because that would result in a duplication of that portion of the annual saving.

DEPRECIATION

Change

In some cases, the accounting procedures of the railroad require the recognition of provision for depreciation; therefore, the annual expenses must include the annual depreciation on selected items of the addition to capital account.

The selected items are usually signals, coal and water stations, new building (for control office), etc.

Value

The depreciation rate varies and has been fixed by the I.C.C. for each railroad. The rate should be obtained from the accounting department.

PER DIEM

Change

It is sometimes possible to determine the number of foreign cars that, as a result of the installation of a signal system, are delivered to another railroad before instead of after "dead-line time" and thus save the per diem billing on those cars.

This information can be obtained by comparing the wheel reports of those trains which the redispatching shows arrive at a transfer point before "dead-line time" in place of as-run after "dead-line time" with the transfer lists and thus count the number of foreign cars which would have been delivered a day earlier. It is then possible to extend the average for the test days into the number per year.

It is much easier to cover this item in the car day saving, because then it is not necessary to segregate the cars of the consists.

Value

As of August 1, 1953, the per diem charge was $2.40.

When this value is applied to the foreign cars, it would be necessary to eliminate the foreign cars when computing the car days saved in order to avoid a duplication of that portion of the annual saving.

ACCIDENT

Change

ANNUAL COST

This item will vary on different railroads due to the previous method of train operation, traffic conditions, open or mountainous territory, amount of obscured view, weather conditions, curves or tangent track conditions, and local conditions peculiar to each installation.

The probable change in accidents, including personal injuries, and the annual cost thereof, is somewhat difficult to forecast, and yet, those accidents which could reasonably have been prevented by the proposed signaling system may be determined with comparative ease by analyzing the accidents which occurred over a period of years sufficient to produce a reasonable and fair yearly average. When this analysis is extensive and made with care, it is reasonable to assume that it is a measure of the long term change and worthy of evaluation.

While one is inclined to think only of major or reportable accidents, sight should not be lost of the non-reportable accidents which occur rather frequently and may amount to an appreciable loss.

INSURANCE VALUE

Signals provide protection against accidents due to track being occupied, open switch points, broken rails, and, in some cases, slides.

In many cases, the value of this protection is intangible in character, and some railroads cover this item in the economic statement as insurance, and place thereon a reasonable and fair value.

Value

The reduced cost of accidents on single-track divisions of two railroads, average for 5-10 years, effected by automatic block signals, averaged $190 to $206 per mile of road per year. A minimum figure of $100 per mile of road per year has been used in some economic reports.

INVESTMENT SAVED

Change

In many instances, the proposed operating method provides additional facilities, capacity, and operating benefits which could only be achieved under the present method of operation by increasing the investment in track, motive power, cars, etc.

It is obvious that the economical solution is that which results in the lowest over-all annual cost, including the yearly amortization of the first cost.

TRACK

Where it is necessary to increase the capacity of the line, and it is the intention to secure this increase by constructing a second main track, but, in the meanwhile, a study is being made to determine the advantages of an alternative signal system, that study should include in the gross saving the interest on the additional investment that would be incurred if the second track were constructed.

MOTIVE POWER

Where larger motive power is being considered to increase the speed of trains in order to get them over the road to improve the competitive position, an alternative study of a signaling system which would accomplish the same result by eliminating delays should include in the gross saving the interest on the cost of the proposed new motive power.

CARS

Where the proposed signal system would eliminate the necessity of purchasing a number of new cars, the gross saving should include the interest on the cost of the new cars.

OTHER FACILITIES

Where the proposed signal system would eliminate the necessity of purchasing some other facility, the gross saving should include the interest on the cost of the other facility.

Value

TRACK

Where possible, the estimated cost of the second main track should be obtained from the records of the railroad. The cost of constructing track will vary depending upon the grading, type of track construction, labor costs, etc.

MOTIVE POWER

Where possible, the cost of the proposed motive power should be obtained from the records of the railroad.

CARS

Where possible, the cost of the proposed cars should be obtained from the records of the railroad.

OTHER FACILITIES

Where possible, the cost of the proposed facility should be obtained from the records of the railroad.

PLANNED EXPENDITURES

Change

There are times when it is contemplated to install a comparatively simple signal system for reasons of safety, which then leads to the question of adding signaling to provide train operation by signal indication, this additional signaling alone being responsible for more or less of the savings outlined herein.

In this case, the economic statement should be prepared with the cost of the installation being only the cost of the additional signaling that would produce the resulting savings.

In other words, it would be grossly unfair to require the savings, and the resulting return on the investment, to justify the total cost of the installation.

That is, items 1-a and 1-b of the economic statement should each be modified by a subitem, "Less planned expenditures."

Value

Obviously, the value of this item should be the installed cost of the comparatively simple system. It will probably have to be estimated on the basis of the records of the railroad.

INTANGIBLES

In addition to the various elements discussed heretofore, there are some savings which are real but are so intangible that the value in money usually cannot be calculated. The following items should be mentioned where and when they apply:

Safety.

Increases safety of train operation, especially during fogs, storm weather, or severe weather conditions.

Reduces the number of train stops which results in less chance of accidents and personal injuries and less damage to locomotives, cars, and lading.

Eliminates the chances of personal injury to trainmen running ahead of the train to open a switch or running to catch the train after closing the switch.

Eliminates the danger of improperly opening a switch in front of or under a train.

Keeps trains in motion a greater portion of the time, which reduces the chances of collisions.

Excess and slow speeds can be checked at all points.

Increases the safety of movement of track motor cars used by employees, because of the closer contact with the dispatcher.

Trains can be stopped readily at frequent locations when the dispatcher is informed of dragging equipment or other unsafe condition.

Broken rails are indicated by lights on the control panel.

Increased safety due to the fact that main line switches will be locked by either a power switch machine or an electric lock.

Less chance for drawbars to be pulled out on account of the fewer stops that would be made. This saves not only the direct cost of the damage, but also the delay to the lading frequently caused by the necessity of setting out the damaged car until repairs are made.

On-time performance.

Provides additional telephones and communication facilities for expediting train movements.

Possibility of progressive improvement in running time.

Information is given at the time and place of action without loss of time.

More complete understanding between the train crews and dispatcher, on account of the direct contact by signal and telephones.

Commercial and competitive aspects.

Improves the competitive position with other railroads and other means of transportation due to quicker delivery, later departure, and reduction in number of failures to meet required market deliveries.

More dependable service.

Sales value to traffic department of the earlier delivery of cars to meet competition.

Other.

Increases the productive time of men on work trains, track cars, etc.

Saves the necessity of more costly alternative improvements.

Provides better facilities to meet sudden demands for increased traffic in emergencies.

Greater flexibility in the movement of work trains, permitting them to utilize the maximum time available.

Provides improvements which conform to the future development of the railroad.

INTEREST

Interest on the capital investment portion of the cost should be computed at the current rate. It will vary with different railroads. It has varied from 2 to 6 per cent in recent economic reports.

ECONOMIC STATEMENT

The economic statement is the summation of the investigation of the foregoing items relevant to the specific study being undertaken. As such, it shows the amount of justification for the expenditure for the signal system in terms of the annual return that system would produce on the investment after paying interest on the money borrowed to make the improvement.

A.A.R. Signal Section Form 24 (Manual Part 29) which follows, is recommended as an outline:

Economic Statement

1. Cost of Installation:
   - (a) Capital Investment .... $..............
   - (b) Operating Expenses ....
   - (c) Total .... $..............
2. Gross Saving per Annum .... $..............
3. Increased Annual Operating Expenses ....
4. Net Reduction in Annual Operating Expenses .... $..............
5. Deduction for Interest Charges @ ....% (of 1-a) ....
6. Net Saving per Annum .... $..............
7. Annual Return over ....% Interest:
   - (a) On Capital Investment (6 ÷ 1-a) ....%
   - (b) On Total Cost (6 ÷ 1-c) ....%

Under Item 1.

The division of the cost in place and in service between 1-a, Capital Investment, and 1-b, Operating Expenses, should be made in accordance with the practice of the accounting department of the railroad.

In general:

A. The total cost of the new property in place and in service should be charged to 1-a, Capital Investment.

Note.—Should the adjustment in B be not tabulated in the interest of simplification, the Operating Expense portion of the total cost would be equal to the Capital Account value of the retired property, and the Capital Investment portion of the total cost would be the remainder.

In other words, instead of charging off the old, merely charge off an equivalent portion of the new—the addition to capital account will be the same.

B. The capital account value of retired property (signal system, track, structures, etc.) should be charged to Operating Expenses and credited to Capital Investment.

C. The cost of removing retired property should be charged to Operating Expenses.

D. The salvage value of retired property should be credited to Operating Expenses.

It is customary to break down the cost figures into Signaling, Telephone, Track, and occasionally Other.

Under Item 2.

While the items which make up the Gross Saving may be tabulated elsewhere in the report and the total only presented here, it may be desirable to make the tabulation here in order that the economic statement be a quick, complete picture.

Under Item 3.

While the items which make up the Increased Operating Expenses may be tabulated elsewhere in the report and the total only presented here, it may be desirable to make the tabulation here in order that the economic statement be a quick, complete picture.

Example
(Based on Form 24)

1. Cost of Installation:			
(a) Capital Investment:			
Signaling (incl. line)	$408,692		
Track	206,100		
Total		$614,792	
(b) Operating Expenses:			
Signaling	$76,726		
Track	56,950		
Total		133,676	
(c) Total Cost of Installation			$748,468
2. Gross Saving per Annum:			
1,739 Train hours	$41.77	$72,638	
0.08 Diesel locomotive		2,568	
0.23 Steam locomotive		2,953	
6,544 Car days	1.75	11,142	
925 Hours road overtime	14.0457	12,992	
73 Hours term. delay	3.54	258	
1,241 #1 Stops	1.25	1,551	
2,555 #2 & #3 Stops	0.34	869	
5 Employees from payroll		15,291	
Total			$120,262
3. Increased Annual Operating Expenses			0
4. Net Reduction in Annual Operating Expenses			$120,262
5. Deduction for Interest Charges @ 3% on $614,792 (1-a)			18,444
6. Net Saving per Annum			$101,818
7. Annual Return over 3% Interest:			
(a) On Capital Investment (6 ÷ 1-a) (101,818 ÷ 614,792)			16.6%
(b) On Total Cost (6 ÷ 1-c) (101,818 ÷ 748,468)			13.6%

Note.—1-c should be reduced by an amount equal to the income tax saving due to the Operating Expense 1-b.

1-c includes a miniature lever relay type interlocking for the rehabilitation of an existing plant.

Economic Statement

(Example)
(Based on Form 24)

1. Cost of Installation:			
(a) Capital Investment:			
Signaling:			
C.T.C.	$743,325		
Retirements	(100,000)		
Telephone additions	3,050		
Track:			
Retirements	(119,900)		
		$526,475	
(b) Operating Expenses:			
Signaling:			
Retirements	$100,000		
Telephone	—		
Track:			
Changes	29,000		
Salvage	(95,200)		
Retirements	119,900		
		153,700	
(c) Total Cost of Installation			$680,175
2. Gross Saving per Annum:			
449 Train hours saved @ $28.42		$ 12,761	
Improvement in local operation at X		5,000	
780 Car days saved @ $1.75		1,365	
Road overtime		504	
312 Stops @ $4.24		1,323	
884 Stops @ $0.24		212	
Payroll saving		32,340	
1 Closed office		300	
Heating closed office		638	
Reduction in track maintenance		8,400	
			$ 62,843
3. Increased Annual Operating Expenses			0
4. Net Reduction in Annual Operating Expenses			$ 62,843
5. Deduction for Interest Charges @ 3% on $526,475 (1-a)			15,794
6. Net Saving per Annum			$ 47,049
7. Annual Return over 3% Interest:			
(a) On Capital Investment (6 ÷ 1-a) (47,049 ÷ 526,475)			8.9%
(b) On Total Cost (6 ÷ 1-c) (47,049 ÷ 680,175)			6.9%

RELATION BETWEEN OPERATING RULES, SPECIAL INSTRUCTIONS, AND SIGNAL SYSTEMS

The economics of railroad operation are directly related to the rules and special instructions which govern that operation. It can be shown in fact that the economics of operation were directly responsible for the development of those rules and instructions. It will be observed from a study of the Standard Code of Operating Rules of the Association of American Railroads, which rules constitute the basic standard for practically all railroad operation in the United States, that safety of operation underlies most of those rules; however, it cannot be overlooked that aside from the humanitarian aspect of safety, which is itself sufficient justification for its practice, the end result of an improved safety of operation is an improvement in the economy of operation. Hence in a treatise on the economics of railway signaling, and because signaling is integral with operation, it is relevant to consider the relation between operating rules, special instructions and signal systems.

In the early days, after railroads had gained acceptance as a transportation agency, it was found that, in many cases, the expenditure attendant to a second track was not justified by the available traffic. Consequently, trains were operated in either direction over the single track. Obviously means had to be provided to meet opposing trains and to permit faster and superior trains to pass. This necessity was met by establishment of sidings. It was also necessary to devise methods to effect these opposing and passing movements without disaster and with a minimum of confusion and delay. The answer was found in arranging for the train movements by time schedules so that the meeting and passing of trains could be prearranged. Thus the "time-table" was born. The time-table constitutes the first system utilized for spacing of trains. In this system each train is given definite rights which have to be respected by all other trains and a schedule is issued by means of which each train crew is notified as to the time of arrival and departure of their train and other trains at specified points. The time-table or schedule system of railroad operation is a time interval system providing for trains to be at the same place at different times. However, the time-table is not now just a "schedule," it incorporates many instructions governing operation of trains over the specific division to which it applies and makes reference to the various methods of operation and the standard rules that will govern.

With the time-table or schedule system of railroad operation, no signal system is involved.

It is apparent that operation under a prearranged time schedule admits of no flexibility and that delays and detentions to traffic would be severe and cumulative, and it was not too long before operation by time schedule was augmented by the written train order which upon issuance had the effect of modifying the prearranged time schedule.

The first train order of record was issued on September 22, 1851, by Mr. Charles Minot, a Superintendent of the Erie R. R. Superintendent Minot was aboard a westward train which pulled into a siding at Turner (now Harriman), N. Y., to meet an eastward train. The eastward train was late. Mr. Minot went to the telegraph office and wired ahead to locate the missing train and learned that it was then at Goshen, 13 miles west. He then sent a message authorizing that train to be held at Goshen and ordered his waiting train to proceed to Goshen for the meet.

Since the issuance of train messages or "train orders" offered a ready means to eliminate many of the deficiencies of the time-table system of operation, this procedure gained rapid acceptance and appropriate rules were drawn to cover. The use of the train order system usually, but not necessarily, requires the use of a signal in the form of either a semaphore, light or flag to indicate orders are to be delivered.

To further facilitate and safeguard train movement the manual block system was developed. This system fundamentally provides that block signals govern the use of the block, but, unless otherwise provided, do not supersede the superiority of trains, nor dispense with the use or observance of other signals whenever or wherever they may be required. The manual block system requires the use of a signal at the entrance to each block and here again appropriate rules had to be drawn to govern train operation under this system.

As the name implies, the operation of a manual block system inherently depended upon the human element for its successful and safe operation. To eliminate the element of human error the automatic block signal system was designed. It was made possible by the development of the track circuit in 1872. This system, as does the manual block system, provides that the use of the block is governed by a block signal, but unless specifically provided the indication of signal does not supersede train rights conferred by time-table or train order, or both. Because the signal at the entrance of a block is automatically controlled, hence does not require an attendant, block spacing can be made shorter and track capacity increased. Here also appropriate rules had to be drawn to govern the train operation under this system.

The development and installation of interlockings required the establishment of further special rules to govern train operation within the limits of the interlocking.

All these many general and special system rules have been developed through long years of operating experience and the Standard Code of Operating Rules of the Association of American Railroads constitutes the basic standard rules for railroad system operation and the reader is referred thereto. Standard rules are essential part of any established or predetermined method of railroad system operation, and consist of operating rules, block signal rules, interlocking rules, time-table rules, etc., all of which should conform to and not conflict with each other. The operation of a railroad is governed by these standard rules issued to all employees affected, in the form of a "Book of Rules." The rules usually follow more or less the standardized form of the Standard Code, and practically without exception contain those particular rules relating to the specific operational systems.

The general operational methods in use are as follows:

1. Time-table and train order system.
2. Time-table and train order with manual block system.
3. Automatic block system.
   - (a) With time-table and train orders—Standard Code Rule 505.
   - (b) Under Standard Code Rule 251.
   - (c) Under Standard Code Rule 261. (Traffic control system)
4. Interlocking. (Standard Code Rule 605)

This method of directing trains is a time interval method and provides authority for the movement of regular trains subject to the rules.

Under normal operation when the trains conform to the time-table schedules there is no delay, but if the schedules are interrupted or extra trains are run, it then becomes necessary to issue train orders to authorize train movements.

Density of traffic will determine the number of train order offices required, and the form of train orders to be issued.

Unless otherwise provided, a fixed signal must be used at each train order office.

Freight and passenger train movements, and "meets," as well as "passes," are made on time-table and train order authority.

In the time interval method of directing train movements, the safety of train operation is dependent upon the exact observance of the many rules governing train operation in the operating book of rules adopted by the railroad, as well as the special instructions in the time-table, bulletins, and otherwise.

When a delay occurs to a train after a "meet" or "pass" has been arranged, the same, or greater, delay is inflicted on the other train because of the difficulty and inflexibility of the system in rearranging "meets" and "passes."

An inherent weakness of any time interval method of operation is that there is no assurance of the existence of the time interval except at the open offices.

The flexibility of operation is in inverse relation to the distance between train order stations and potential delay is in direct relation to the distance between the train order stations, while the cost of operation is in direct relation to the number of train order stations.

TIME-TABLE AND TRAIN ORDER WITH MANUAL BLOCK SYSTEM

The Standard Code defines Manual Block Signal System as: A block or a series of consecutive blocks, governed by block signals operated manually, upon information by telegraph, telephone, or other means of communication.

Manual block is a method of spacing trains in which the signals or other means of displaying indications, normally at stop, are operated manually, without electrical or mechanical check, subject only to the rules.

The manual block system is usually a supplement to time-table and train order operation. The block signal may be the train order signal.

The system is flexible to the extent that the facilities provided can be either increased or decreased as traffic warrants by either shortening or lengthening the blocks.

Trains may be permitted to follow one another into a block, although an absolute block is generally maintained for passenger trains. In the latter case, it is essential to have short block sections and sufficient block offices to expedite traffic without delays.

Railroads adopted the manual block system in an endeavor, even at the expense of additional block offices, to surround train operation with greater safety, particularly passenger trains, than is possible in the time interval method.

On light traffic lines, block lengths of 5 to 7 miles do not cause excessive delays, but, with a traffic density of 20 or more trains per day, the use of an absolute block for passenger trains, which permits only one train in the 5 or 7-mile block section, results in considerable delay time.

The addition of block stations to reduce the delay results in a relatively high cost of operation.

AUTOMATIC BLOCK SYSTEM

The Standard Code defines Automatic Block Signal System as: A series of consecutive blocks governed by block signals, cab signals, or both, actuated by a train, or engine, or by certain conditions affecting the use of a block.

With the train order and manual block systems, the safe operation of the system is more or less dependent upon the human element. With the automatic block system, the train automatically controls the signals.

The fundamental element of the automatic block system is the continuous track circuit which provides an economical and safe method of maintaining a space interval between following and opposing train movements. The space interval or block may vary between a few hundred feet to two or more miles.

Where trains are operated under Standard Code Rule 505 and neither Standard Code Rule 251 or 261 is in use, the automatic signals do not supersede the superiority of trains, and train movements are made on time-table and train order authority. On two or more tracks the signals provide for permissive following movements in the direction of traffic, while on single track it is usual for the signaling to be so arranged as to provide for permissive following movements and absolute block for opposing movements between adjacent sidings.

Under normal operation when the trains conform to the time-table schedules there is no unusual delay, but if the schedules are interrupted or extra trains are run, it then becomes necessary to issue train orders to govern train movements. When a delay occurs to a train after a "meet" or "pass" has been arranged, the same, or greater, delay is inflicted upon the other train because of the difficulty and inflexibility of the system in rearranging "meets" and "passes."

The flexibility of operation is in inverse relation to the distance between train order stations, and potential delay is in direct relation to the distance between train order stations, while the cost of operation is in direct relation to the number of train order stations.

Where Standard Code Rule 251 is in effect, the block signals supersede superiority of trains, and train orders are only required for movements against the current of traffic, such movements also being made under manual block rules.

Where Standard Code Rule 261 is in effect, movements are made in both directions on the same track by block signals whose indications supersede the superiority of trains so that train orders are no longer required.

The requisites for installation of automatic block signaling are as follows:

1. All control circuits, the functioning of which affects safety of train operation, shall be designed on the closed circuit principle, except circuits for roadway equipment of intermittent automatic train stop system.

2. Each roadway signal shall be located over or to the right of the track it governs.

3. Aspects shall be shown by the position of semaphore blades, color of lights, position of lights, flashing of lights, or any combination thereof. They may be qualified by marker plate, number plate, letter plate, marker light, shape and color of semaphore blades or any combination thereof, subject to the following conditions:

(a) Night aspects of roadway signals, except qualifying appurtenances, shall be shown by lights; day aspects by lights or semaphore arms. A single white light shall not be used.

(b) The fundamental indications of signal aspects shall conform to the following:

1. A red light, a series of horizontal lights, or a semaphore blade in a horizontal position shall be used to indicate Stop.

2. A yellow light, a lunar light, or a series of lights or a semaphore blade in the upper or lower quadrant at an angle of approximately 45 degrees to the vertical, shall be used to indicate that speed is to be restricted and stop may be required.

3. A green light, a series of vertical lights, or a semaphore blade in a vertical position in the upper quadrant, or 60 or 90 degrees in the lower quadrant shall be used to indicate Proceed at Authorized Speed.

4. Each roadway signal shall be located with respect to the next signal or signals in advance which govern train movements in the same direction so that the indication of a signal displaying a restrictive aspect can be complied with by means of a brake application, other than an emergency application, initiated at such signal, either by stopping at the signal where a stop is required, or by a reduction in speed to the rate prescribed by the next signal in advance where reduced speed is required.

5. The failure of a lamp in a light signal, or a semaphore signal arm assuming a false restrictive position, shall not cause the signal to display a more favorable indication than intended.

6. The battery or power supply for each signal control relay circuit, where an open-wire line circuit or a common return circuit is used, shall be located at the end of the circuit farthest from the relay.

7. Signals shall be controlled automatically by track circuits extending through the entire block.

8. Signal governing movements over hand-operated switch in the facing direction shall display its most restrictive aspect when the normally closed point is open ¼ inch or more and, in the trailing direction, ⅜ inch or more, except that where a separate aspect is displayed for facing movements over the switch in the normal and in the reverse position, the signal shall display its most restrictive aspect when the switch points are open ¼ inch or more from either the normal or reverse position.

9. At hand-operated crossover between main tracks, protection shall be provided by one of the following:

(a) An arrangement of one or more track circuits and switch circuit controllers.

(b) Facing point locks on both switches of the crossover, with both locks operated by a single lever.

(c) Electric locking of the switches of the crossover.

10. Signals governing movements over either switch of the crossover shall display their most restrictive aspect when any of the following conditions exist:

(a) Where protection is provided by one or more track circuits and switch circuit controllers, and either switch is open or the crossover is occupied by a train, engine, or car in such a manner as to foul the main track.

(b) Where facing point locks with a single lever are provided, and either switch is unlocked.

(c) Where the switches are electrically locked, before the electric locking releases.

11. On track signaled for movements in both directions, a train shall cause one or more opposing signals immediately ahead of it to display an aspect requiring a stop. On such track, signals shall be so arranged and controlled that if opposing trains can simultaneously pass signals displaying proceed aspects, and the next signal in advance of each such signal then displays an aspect requiring a stop, the distance between opposing signals requiring a stop shall be not less than the aggregate of the stopping distances for movements in each direction. Where such opposing signals are spaced stopping distance apart for movements in one direction only, signals arranged to display restrictive aspects shall be provided in approach to at least one of the signals. Where such opposing signals are spaced less than stopping distance apart for movements in one direction, signals arranged to display restrictive aspects shall be provided in approach to both such signals.

12. The circuits shall be so installed that each signal governing train movements into a block will display its most restrictive aspect when any of the following conditions obtains within the block:

(a) Occupancy by a train, engine, or car.

(b) When points of a switch are not closed in proper position.

(c) When an independently operated fouling point derail equipped with switch circuit controller is not in derailing position.

(d) When a track relay is in de-energized position, or when signal control circuit is de-energized.

13. Signal control and electric locking circuits shall not be selected through the contacts of instruments designed primarily for indicating or annunciating purposes in which an indicating element attached to the armature is so arranged that it can in itself cause improper operation of the armature.

14. Dragging equipment and slide detectors and other similar protective devices shall be arranged to operate in conjunction with the automatic block signal system.

INTERLOCKING

The Standard Code defines Interlocking as: An arrangement of signals and signal appliances so interconnected that their movements must succeed each other in proper sequence and for which interlocking rules are in effect. It may be operated manually or automatically.

Its use is largely influenced by considerations of economy. It was early recognized as a necessity in the large passenger terminals because the cost of switchmen to operate the hand-throw switches became excessive and the possibility of collisions due to fog, bad weather conditions and the delays to guard against accidents, often placed serious limitations on traffic. Interlockings were also found advantageous at yards, junctions, crossings, and other points as a means of eliminating train stops.

Automatically controlled signals and other signaling devices for the protection of train movements over railroad grade crossing and other simple layouts came into considerable prominence about 1923. These installations operate upon the approach of a train and are called "automatic interlockings." This type of signaling not only eliminates the necessity for attendants for operation of the interlocking, but also the interlocking machine, other interlocking appliances, the interlocking station and other buildings, and in addition saves the yearly cost of maintaining and operating these facilities.

The requisites for installation of interlocking include those for installation of automatic block signaling in so far as they apply and in addition the following:

1. Track circuits and route locking shall be provided throughout interlocking limits.

2. The control circuit for power-operated, or slotted mechanical, signal governing movements at higher than restricted speed over switches, movable point frogs, and derails shall be selected through circuit controller operated directly by switch points or by switch locking mechanism, or through relay controlled by such circuit controller, for each switch, movable point frog, and derail in the routes governed by such signal. Circuits shall be so arranged that such signal can display an aspect to proceed only when each such switch, movable point frog, and derail in the route is in proper position.

3. Mechanical locking, or the same protection effected by means of circuits, shall be provided.

4. The control circuits for aspects with indications more favorable than Proceed at Restricted Speed shall be selected through track relays for all track circuits in the route governed or through repeating relays for such track relays. At automatic interlocking, signal control circuit shall be selected as follows:

(a) Through track relays for all track circuits in the route governed and in all conflicting routes within interlocking limits or through repeating relays for such track relays.

(b) Through signal mechanism contacts or relay contacts closed when signals for such conflicting routes display stop aspects.

(c) Through normal contacts of time releases for such conflicting routes or contacts of relays repeating the normal position of contacts of such time releases.

5. Approach or time locking shall be provided in connection with signals governing movements at higher than restricted speed.

6. Facing point lock or switch-and-lock movement shall be provided for mechanically operated switch, movable point frog, or split point derail.

7. Indication locking shall be provided for operative approach signals of the semaphore type, power-operated home signals, power-operated switches, movable point frogs, and derails, and for all approach signals, except light signals all aspects of which are controlled by coded track circuits or by double wire line circuits.

8. Signals shall be provided to govern the train movements into and through interlocking limits.

9. Mechanical or electric locking or electric circuits shall be installed to prevent signals from displaying aspects which permit conflicting movements

except that opposing signals may display an aspect indicating Proceed at Restricted Speed at the same time on a track used for switching movements only, by one train at a time.

10. At automatic interlocking, a loss of shunt for 5 seconds or less shall not permit an established route to be changed.

11. A signal shall be provided on main track to govern the approach with the current of traffic to any home signal except where the home signal is the first signal encountered when leaving yard or station and authorized speed approaching such signal is not higher than slow speed. When authorized speed between home signals on route governed is 20 miles per hour or less, an inoperative signal displaying an aspect indicating Approach next Signal Prepared to Stop may be used to govern the approach to the home signal.

12. Electric lock shall be provided for each hand-operated switch or derail within interlocking limits, except where train movements are made at not exceeding 20 miles per hour. At manually operated interlocking it shall be controlled by operator of the machine and shall be unlocked only after signals governing movements over such switch or derail display aspects indicating Stop. Approach or time locking shall be provided.

13. Power machine for operating derails, devices which check the surface and alignment of rails, check bridge locking mechanism, or operate bridge circuit controller shall be provided with means to indicate on interlocking machine or to the operator when movement is completed and unit is locked.

14. Signal appliances shall be so interlocked with bridge devices that before a signal governing movements over the bridge can display an aspect to proceed the bridge and track must be aligned and locked, with the bridge locking members within 1 inch of their proper positions and with the track rail on the movable span within 3/8 inch of correct surface and alignment with the rail on the bridge abutment or fixed span.

15. Signal devices shall be so interlocked or interconnected with bridge devices that no bridge device can be operated unless all signal devices have properly functioned to release the bridge.

CENTRALIZED TRAFFIC CONTROL

The Signal Section, A.A.R., defines Centralized Traffic Control as: A term applied to a system of railroad operation by means of which the movement of trains over routes and through blocks on a designated section of track or tracks is directed by signals controlled from a designated point without the use of train orders and without the superiority of trains.

Centralized traffic control is a method of train operation by signal indications which makes it economically possible to greatly extend the territory controlled from one station. This system of train operation is considered by many to be among the outstanding developments in the railroad field and is extensively used as a means of directing trains because of the economy in operation which it effects. It not only affords direct economies in transportation, but it makes possible a more intensive use of track facilities, motive power, cars, manpower, etc.

It is therefore a system of operation under automatic block Standard Code Rule 261 and interlocking Standard Code Rule 605, or a traffic control system operated from a central control point.

Centralized traffic control basically involves the control of signals governing the use of consecutive blocks from a central point and provides for the movement of trains by authority of the signals so controlled. Most installations include the power operation of switches because of additional advantages which come about through the elimination of train stops; however, the power operation of the switches is not an inherent requirement; they may be either hand or spring-operated.

Inherent in a centralized traffic control system is the combination of the utility of interlocking control of switches and the protection of automatic block signaling.

The greatest saving produced by centralized traffic control is the elimination of train orders and the substitution therefor of operation by signal indication, which results in a reduction of the time lost in sidings due to conditions unforeseen by the dispatcher in arranging meets, by train crews clearing superior trains, and the inability with other methods of operation to quickly change rights, meeting points, etc., as changing conditions dictate.

The time element in the transmission of orders is practically eliminated, which results in more efficient dispatching. Direct control of each train movement is made possible without dependence upon a system of control involving intermediate operators for the delivery of orders. The train order in the signal indication method is given by the signal to the engineman at the point and time desired.

The requisites for installation of centralized traffic control or other traffic control systems include those for automatic block signaling and interlocking in so far as they apply and in addition the following:

1. Signals governing movement at higher than restricted speed shall be controlled by continuous track circuits extending through the entire block. Also, in addition, at controlled point they shall be controlled by control operator, and, at manually operated interlocking, manually in cooperation with control operator.

2. On track signaled for movements in both directions, occupancy of the track between opposing signals at adjacent controlled points shall prevent changing the direction of traffic from that which obtained at the time the track became occupied.

3. Signals at a controlled point shall be so interconnected that aspects to proceed cannot be displayed simultaneously for conflicting movements.

4. Signals at adjacent controlled points shall be so interconnected that aspects to proceed cannot be displayed simultaneously for conflicting movements.

5. Means shall be provided to insure that after a signal has been cleared, and the locking is effective, it cannot be restored manually to Stop by the operation of any lever other than its controlling lever.

6. Occupancy of track circuits at controlled points shall be automatically indicated at the control station.

7. Approach or time locking shall be provided for all controlled signals and for all electric locks on hand-operated switches.

8. Means shall be provided to indicate on the control machine when power-operated switch has completed its movement and is locked.

9. Each hand-operated switch in main track where train movements are made at speeds exceeding 20 miles per hour shall be electrically locked in normal position.

CAR RETARDERS

Originally freight cars were classified in flat switching yards but in order to increase yard handling capacity and promote efficiency and economy, hump or gravity yards were provided. With this method of car classification after a car was cut off at the crest of the hump it would accelerate down the hump by gravity, with rider controlling the speed with the hand brake. Switches were handled manually and later changed to power operation with control from one location, as a means of increasing efficiency and economy. A later improvement for efficient and economic freight car classification is the car retarder for controlling speeds without the use of riders.

The car retarder is a braking device, usually power-operated, built into a railway track to reduce the speed of cars by means of brake shoes which, when set in braking position, press against the sides of the lower portions of the wheels. The car retarder system includes the retarders, the power-operated switches, control machines, power supply, and sometimes power-operated skate placing mechanisms at the hump end of each classification track for stopping cars in emergency. The number and location of car retarders and operating stations depends upon the track layout and profile. In general, however, the first retarder is near the summit of the hump; others are at intervals along the leads. The car retarder operators also operate the switches of the classification tracks, judge the speed of the cars, retard them when necessary by means of the car retarders, and, if necessary, operate the skate machines. However, the latest electronic developments of automatic switching and retarder speed control minimize the manpower requirements.

RAILROAD-HIGHWAY GRADE CROSSING PROTECTION

Prior to the advent of the automobile, the protection of highway grade crossings with railroads was generally confined to the installation of warning signs indicating the location of the crossings except at the more heavily traveled crossings where watchmen, gates, or bells, were installed to indicate the approach of trains. However, the rapid development of improved highways and the increasing automobile registration has introduced new problems. The greater automobile traffic at night and in the early morning hours has greatly increased the cost of watchmen and gatemen for continuous service and resulted in excessive costs of operation and maintenance. The rapid increase in the number of highway crossings where it has become necessary to provide warning of the approach of trains and the necessity for economy led to the development of automatic crossing protection devices which have a low yearly maintenance cost as compared with the previous types of protection. These devices can be more widely used than more expensive means of protection, thereby reducing the hazards of accidents at the maximum number of crossings.

The recommended standards and practices for new installations of railroad-highway grade crossing signs, signals and automatic gates, are shown in A.A.R. Joint Committee on Grade Crossing Protection Bulletin No. 4.

In addition to providing more economical protection, automatic railroad-highway grade crossing signals provide more efficient protection than the type replaced, and provides 24-hour protection whereas, in many cases, the protection replaced was only for a portion of the day. In certain cases auto-manually controlled signals have been used and in other cases manual control has made it possible to make substantial saving in operating expenses.

In considering the economics of railroad-highway grade crossing protection, no attempt is made to evaluate the safety features in dollars. The relative advantages of one type of protection over another in dollar costs is considered rather than the question as to whether protection is required. The railroad does not in all cases have the final word as to the type of protection to be installed but in many cases can choose between several alternatives. It is, of course, to the interest of the public and the railroad to provide the most economical solution to the highway traffic problem. Ordinarily, however, it will be found that the use of automatic crossing signals will provide the most desirable protection even at points where traffic conditions are unusual.

GRAPHIC TRAIN CHART

A reproduction of a portion of a form, one-half reduction, found to be very convenient for the preparation of graphic train charts is shown in Fig. 9.

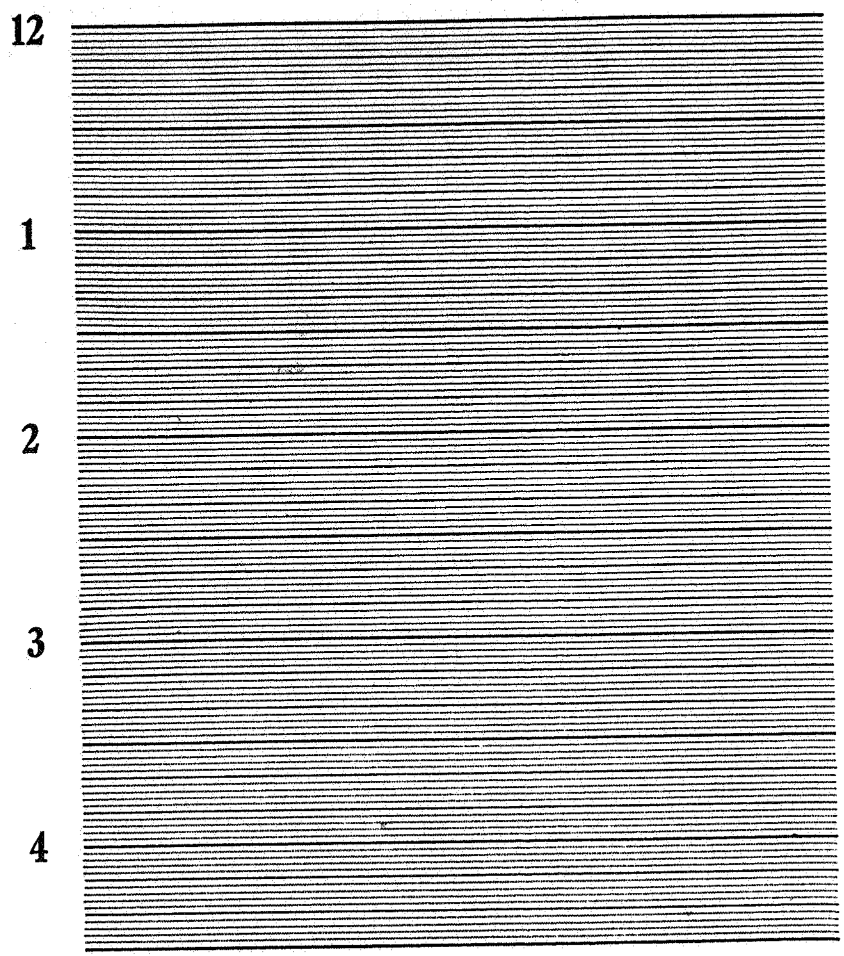


Fig. 9.

The actual dimensions of this chart are such that when it is photostated to half size and then folded once each way it can be trimmed to 8½ inches by 11 inches.

The horizontal rules are 30 inches long, and from the top to bottom rules is 41 inches. The figures, 12, 1, 2, 3, etc. represent the hours of the day beginning at 12:00 midnight and ending at 12:00 midnight. Between adjacent lines represents 2 minutes. The weighting of the lines as shown has been found to be advantageous.

The over-all size of the sheet is 36 inches by 48 inches.

When distance is laid out horizontally to scale, a scale of 1 inch equals 4 miles, a territory of 120 miles can be handled on one sheet.

This sheet and the above mentioned scales have been found satisfactory for a wide variety of conditions.

Note.—Some investigators have made a tracing ruled similar to the above, except with rules either 21 or 25 inches long and a time scale of 2.5 inches per hour. Others use standard cross-section paper and scales to suit the conditions.

Following this page is a 50 per cent reproduction of a portion of an actual graphic train chart made on this form.

Typewritten notes point out the various symbols used.

When making a chart, the following procedure will be found advantageous:

Indicate the times recorded on the dispatcher's train sheet using a tick mark for a "by" time and a solid line loop when both the arrival and departure are given for a station.

Draw in the passenger trains for one direction and then the other direction, using a solid line between recorded times when that performance appears reasonable, and a dash line where it is necessary to insert a stop (for either a station stop or a meet or a pass) which occurred between the recorded times.

Draw in the freight trains in one direction and then in the other, using a solid line when the performance appears reasonable and a light construction (solid for the moment) line where the performance seems unreasonable.

Check the conductor's delay reports (Fig. 2, page 8), as well as the notes on the dispatcher's train sheet, and modify the light construction lines using a solid line if the conductor's delay reports include the arrival and departure time at a station and the performance appears reasonable, and a dash line if the conductor's delay report gives only the length of time spent at a station and it is necessary to estimate the time of arrival and departure.

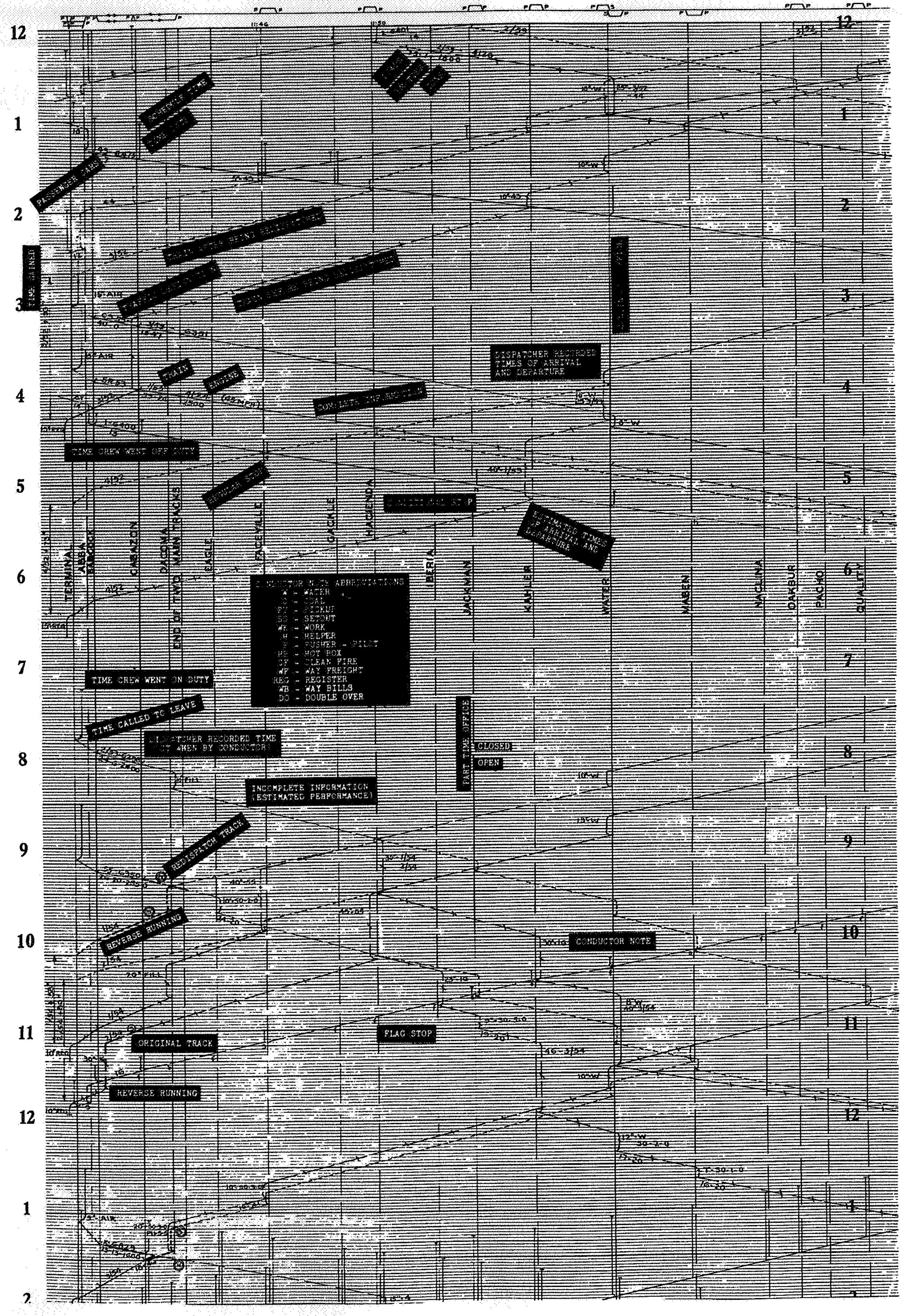
Should the performance of a particular train still not look reasonable, a study of the conductor's wheel report (Fig. 1, page 6) may be desirable in order to determine whether a set-out or pick-up was made even though the conductor's delay report did not show time spent at that station.

There are times when the performance of a particular train does not seem reasonable on the basis of the above procedure; therefore, it is well to check with either the trainmaster or a dispatcher to ascertain what might have happened, because regular occurrences such as a stop for inspection might not be considered unusual by the conductor and therefore not listed on his delay report.

Of course, where a train does not make meets or passes as originally run and probably will not when redispatched and the performance does not look reasonable, there is little point in spending much time trying to get its detailed performance when it will not influence the redispatching.

The schedule times for the first-class trains, obtained from the time-table in effect for the days plotted, are useful in analyzing the probable thinking of the crews of conflicting movements, the reason why delays occurred, and the saving that probably would have been made with the modern system of signaling. For example, around 4:40 a.m. at Kahler 4/52 waited for both 1/53 and 1, when there appears to have been time for

NORTH SOUTH RAILWAY CO.
GRAPHIC TRAIN CHART
TERMINAL TO QUALITY, TENN.



4/52 to go to Jackman. Having the schedule time for 1 at Jackman, one can clearly see that the crew of 4/52 decided they could not get into the siding at Jackman sufficiently ahead of 1's schedule and waited.

After completing the above it is well to ink in the chart before proceeding with the redispatching so that any erasures made during the redispatching will not result in a loss of any of the original data. Inking at this point also has the advantage that in redispatching one can draw solid lines and instruct the draftsman to make them all dotted.

As a train is redispatched and its new time distance curve drawn in as a dotted line, the corresponding portion of the old time distance line should be crosshatched to indicate the change.

SPEEDS OF TRAINS THROUGH LEVEL TURNOUTS*

The following tables show speeds through level turnouts giving riding conditions equivalent to those obtained in traversing a curve elevated 3 inches less than that required for equilibrium; when the center of gravity of equipment is 84 inches above the rail, the resultant of forces will intersect the plane of top of rail approximately 6 inches outside the center line of the track.

Speeds through turnouts with either straight or curved switch points are calculated from formula $E = 0.00066\,D\,V^2 - 3$, (See A.R.E.A. Manual page 5-3-9) where D equals the degree of curvature of the closure curve or the switch curve, whichever is sharper; for turnouts with straight switch points, D for the switch point curve is the degree of curvature of a curve having a central angle equal to the switch angle and a chord length equal to the length of the switch points.

Turnouts With Straight Switch Points (A.R.E.A)

Turnout Number	Length of switch points	Speed in miles per hour: Lateral turnouts	Speed in miles per hour: Equilateral turnouts
5	11′-0″	12	----
6	11′-0″	14	----
7	16′-6″	17	----
8	16′-6″	19	----
9	16′-6″	21	----
10	16′-6″	21	29
11	22′-0″	27	38
12	22′-0″	27	39
14	22′-0″	27	39
15	30′-0″	37	52
16	30′-0″	38	53
18	30′-0″	38	53
20	30′-0″	38	53

Lateral Turnouts With Curved Switch Points (A.R.E.A)

Turnout Number	Length of switch points	Speed in miles per hour
5	13′-0″	12
6	13′-0″	15
7	13′-0″	18
8	13′-0″	21
9	19′-6″	22
10	19′-6″	25
11	19′-6″	28
12	19′-6″	29
14	26′-0″	35
15	26′-0″	39
16	26′-0″	41
18	39′-0″	46
20	39′-0″	51

* A.R.E.A. Construction and Maintenance Section Manual, Chapter 5 (1953).

EQUATED TRACK VALUES FOR LABOR DISTRIBUTION *

1. The table of comparative track values is recommended for general guidance in allocating labor on territories where all conditions are approximately alike, and its use will aid in distributing maintenance allowances to greater advantage than would otherwise be the case.

2. No table of track values can be sufficiently specific to meet all conditions of railways or portions of railways having varying traffic, physical, or other basic characteristics. Hence, the use of the table is subject to limitations when so applied.

Comparative Track Values

First main track, mile	1.00
Second main track, mile	0.83
Third and fourth main track, mile	0.75
Branch line track, mile	0.49
Passing and thoroughfare track, mile	0.43
Yard and side track, mile	0.32
Main track switch, each	0.07
Side track switch, each	0.05
Railroad crossing, each	0.10
Paved street or highway crossing, each	0.07
Unpaved highway crossing, each	0.03
Unimproved road crossing, each	0.01

* A.R.E.A. Construction and Maintenance Section Manual, Chapter 22 (1953).