Locating Automatic Block Signals for Heavy Traffic*

Last of Two Installments, Treats of the Relation of Speed, Train Length and Headway to Signal Spacing

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THE train operating characteristics, including the accelerating and braking speeds as influencing the spacing of signals, was explained in detail with diagrams in the first installment of this article, published in the September issue of the *Railway Signal Engineer.*

At approximately 16 m.p.h. the car motors are connected in multiple and the rate of acceleration above this point varies with the speed, finally reaching the limiting speed when the tractive effort just balances the grade and train resistance. The acceleration rate at any speed above 16 m.p.h. is shown in Fig. 9. The curves are all straight lines and are derived by subtracting the train resistance plus the grade resistance balancing efforts from the tractive effort developed by the car motor. The rates of acceleration are determined thus: For example, assume that the train has reached a speed of 19 m.p.h. and continues on a + 1 per cent grade; the rate of acceleration for the continuing movement is found by referring the point of intersection of the + 1 per cent grade line with the 19 m.p.h. speed line, to the acceleration scale on the diagram which we observe to be 0.91 m.p.h. per second. Continually decreasing rates of acceleration are found by referring to the successive intersections as before until the speed of 33 m.p.h. is reached, which is the limiting speed for a + 1 per cent grade.

Figure 9 serves added usefulness in determining negative rates of acceleration, that is, slowing up. For example, if a train be moving at a speed in excess of the limiting speed for the grade which it encounters, the train will slow up and the rate of slowing up is found thus: Assume the speed to be 40 m.p.h. and the grade entered to be + 6 per cent, follow down the speed line for 40 m.p.h. until it intersects the dotted diagonal line for + 6 per cent grade and project a horizontal line to the left and the acceleration is found to be 1.15 m.p.h. per second except that it is negative acceleration—now following down the dotted diagonal line and projecting the several intersection points to the left we find a continually decreasing rate of slowing up until 18½ m.p.h. speed is reached, which is the limiting speed for a + 6 per cent grade.

Train Length, Speed and Headway

Figure 10 shows the very intimate relation between train length, minimum headway and speed. The curves set forth the relation existing between speed, free running headway and length of train for a level track road with no signals, the same road equipped with a two block overlap signal system and the same road equipped with a one block overlap signal system.

We have previously mentioned that the ability to run trains depends on the ability to protect them, and in the curves shown hereon consideration has been given to providing suitable braking distance, which has been assumed as emergency braking distance 50 per cent for the speed concerned. Curves *d, e, f, g, h* and *i* are based on the assumption that the signal system is two block indication and also include an element of time which is provided to allow for the signal equipment to change the indication after the preceding train had passed out of the control, and to allow for the identification of the signal by the following train. This time has been assumed at 2½ sec. in each case of a total of 5 seconds. The 2½ sec. time allowance for identification of the green signal provides a sighting distance proportional to the speed and this distance, as will be noted by referring to the inset curve, varies from 55 ft. at a speed of 15 m.p.h. to 185 ft. at 50 m.p.h.

Curve *A* establishes the relation existing between speed and headway when a train is considered as a point only

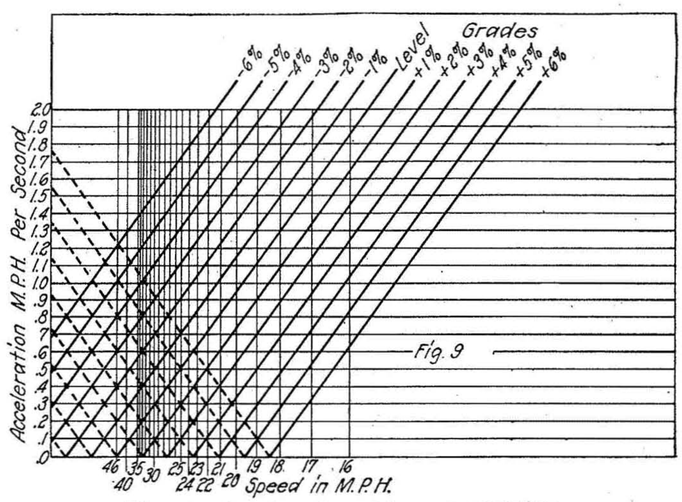

Fig. 9. Acceleration Above 16 M.P.H.

and is the only curve with zero point of origin. This is the fact, because at zero speed, zero train length requires no braking distance. When the element of *speed* is introduced we must also provide the element *braking distance* and the trains must be spaced apart. When the trains are separated by any distance, however small, time must be allowed for the train to run this distance, thereby introducing the element *headway,* which is found by referring to the intersection of the speed line with this curve to the scale at the bottom. For example, with a speed of 35 m.p.h. the headway will be 10 sec.

Curve *B* establishes the relation existing between speed and headway when the element of train length is introduced and for illustrative purposes a three-car train is assumed and the headway is found as before. Curve *B,*

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however, does not originate at zero, because, having introduced the element train length, we must provide an amount of time for the train to run its own length. This time will be less with the higher speeds and consequently affects headway less because the time required to run a train length is small compared to the time required to run the braking distance necessary at the higher speeds. As the speed is lowered, the required braking distance is shortened, but the time required to run a train length is increased, eventually resulting in a speed point being reached beyond which a reduction in speed can only result in increased headway; in other words, the time required to run a train length becomes the controlling factor. This accounts for the shape of curve *B*. The point at which this change of conditions become effective is

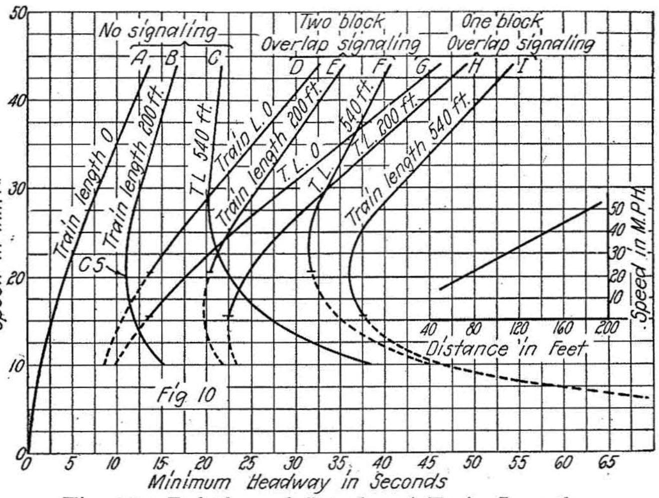

Fig. 10. Relation of Speed and Train Length

known as the "Critical speed," located approximately at the point *CS* and no increase or decrease in speed can take place without increasing the headway. The critical speed for a three-car train is, therefore, 20 m.p.h. and the closest possible headway is approximately 11 sec.

Curve *C* is shown to illustrate the comparative values in effect when the train is increased to 8 cars. The critical speed is 27½ m.p.h. and the headway approximately 20¼ sec. Curves *A*, *B* and *C* illustrate the relations for a level track road without signals and in order to arrive at the results shown, many conditions at present impossible of attainment must be overcome. Among these are found the automatic interlocking of train movement so absolute that a following train will synchronize with the preceding train with respect to acceleration, coasting and braking operation.

Curves *D*, *E* and *F* illustrate the relations for 0, 3 car and 8 car train operation on a level track road when controlled by two block overlap signal system and curves *G*, *H* and *I* show the relation for 0, 3 and 8 car train operation on a level track road when controlled by a one block overlap signal system and show with rather marked clearness the influence of signaling on train operation when the signaling is considered from a scientific standpoint.

The lower portions of curves *D* to *I* are shown dotted. The reason for this is that at the lower speeds the block length necessary to maintain capacity becomes less than 66 ft. and since lowering the speed will result only in increased headway the advantage gained is so slight as to be overbalanced by the practical disadvantage of the very short block.

For comparative purposes these curves show a correct basis for a number of interesting conclusions, among which are:

1. That the train capacity of a road operated to the maximum without signals, and consequently without protection, will in every case be reduced by the introduction of signaling.
2. That there is a speed at which trains must be run in order to utilize the track to capacity and any variation from that speed can only result in reducing the maximum train capacity. This statement is a fact regardless of whether the road is signalled or not.
3. With a given speed, increasing the train length increases the headway and reduces the train capacity.
4. In order to obtain maximum train capacity with increased train length increased speed is necessary.
5. That in order to obtain maximum train capacity the speed must automatically be limited to the critical speed, in which event any disorganization of the operating schedule due to delay of one train cannot be cleared up.
6. That maximum car capacity and consequently maximum passenger carrying capacity of a train vary with train length and, of course, increase with the train length.

Application of Data to Location of Signals

The curves shown in Figs. 1 to 4 contain all the information necessary to locate a train with respect to the maximum speed attainable and the distance required in which to accelerate the train to the maximum speed. For the purpose of locating signals additional curves showing the position of the trains with respect to time are necessary, but as time is but the result of dividing the distance passed over by the speed the development of a time distance curve will be covered in connection with the working drawings Figs. 11 and 12.

The problem of providing a signal system may be put up to the signal engineer in any one of several forms, but in any event three basic elements are necessary: (1) Number of trains per hour or (more properly stated) minimum headway; (2) maximum length of train, and (3) maximum length of station stop. With respect to

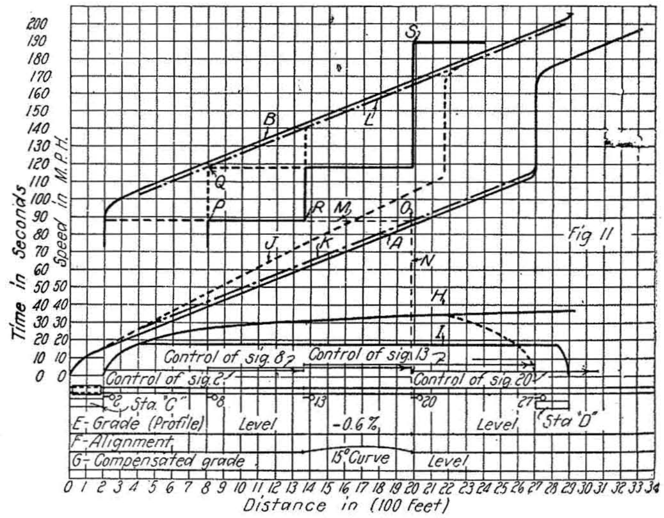

Fig. 11. Signals, Located By Time-Distance

the second element, maximum length of the train, the headway between trains is the time interval elapsing between the time the front of one train passes a given point and the time the front of the following train passes the same point. The train may be made up of one car in which case the time required for the train to run its own length is small. A slow moving train of considerable length may therefore prove a sizable factor in the design of a signaling system and increases in importance as the headway is reduced.

With no station stops the problem is simple. However, the length of the station stop is the controlling element, because, as has been pointed out, the maximum capacity of any line can be attained only by continuous operation at a definite speed. To stop a train for any reason will result in lengthening the headway: (1) by the time required to decelerate; (2) the time the train is stopped, and (3) the time required to accelerate the train back to the definite speed.

The Elements of the Solution

The method of locating signals for non-stop train operation at definite speeds is simple and may be shown clearly without resort to curve diagrams. For example, a train moving at a definite speed requires that a definite distance be provided within which it may be stopped. This distance is proportional to the speed and together with an excess distance constituting a margin to offset deficiencies in braking equipment and poor track conditions, fixes the spacing of signals if maximum track capacity is to be attained. The mimimum headway available will, of course, be the time required for the train to run its own length plus the time for signal equipment operation and identification, plus the time required for the train to run three blocks of the previously determined length. If the value thus determined for headway is less than the required headway the block length may be increased to meet actual headway requirements and thus keep down the cost of the signal system. If the value is greater, resort must be had to more than one block overlap, as will be appreciated by reference to Fig. 10. But in any case the "Caution" control of any signal must extend at least the required braking distance beyond the next signal.

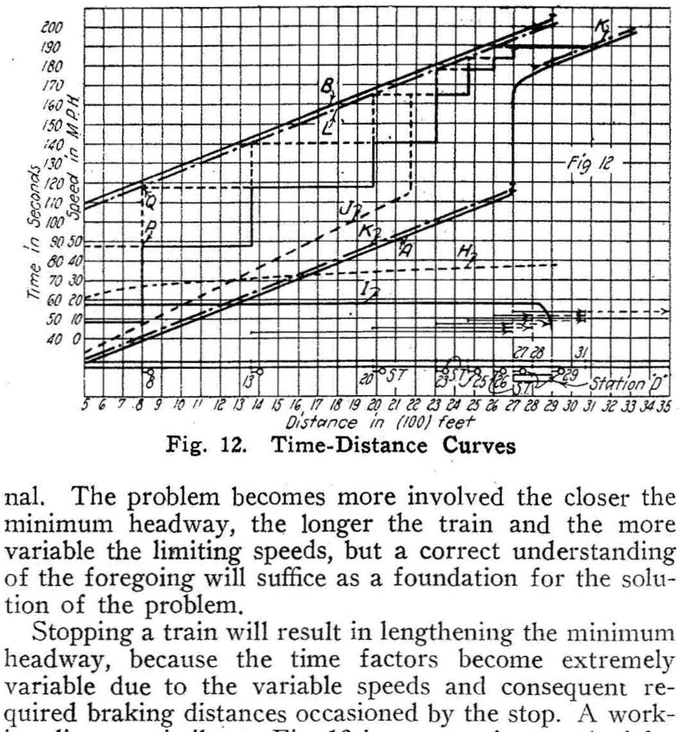

Fig. 12. Time-Distance Curves

nal. The problem becomes more involved the closer the minimum headway, the longer the train and the more variable the limiting speeds, but a correct understanding of the foregoing will suffice as a foundation for the solution of the problem.

Stopping a train will result in lengthening the minimum headway, because the time factors become extremely variable due to the variable speeds and consequent required braking distances occasioned by the stop. A working diagram similar to Fig. 13 is a convenient method for setting forth the influences.

Fig. 13 shows the completed design for a signaling system to meet the requirements of the following specification:

Minimum headway, 90 sec.
Maximum train length, 200 ft.
Maximum station stop at Station D, 50 sec.
Operating time of signal equipment, 2½ sec.
Signal system to be, 3 position.
Time required for identification of "Proceed' signal, 2½ sec.
Braking distance plus a margin to be provided for the protection of the preceding train.

In order to set forth more clearly the method of arriving at the results here shown we have prepared two diagrams showing, in greater detail, the successive steps involved. At the lower part of Fig. 11 is shown the track, below which are lines *E*, *F* and *G*, representing respectively the grade (profile), alignment and compensation grade; that is, grade and alignment reduced to terms of grade. In order to avoid complication in the other curves and to simplify the description we have shown a —0.6 per cent grade and a 15 degree curve of exactly the same limits. These two conditions balance each other to produce a compensated level grade.

Stations *C* and *D* are located as shown and are each 200 ft. in length to provide for the 200-ft. train. Starting with the acceleration curve, previously developed, it will be clear that if power is continuously applied to the motors of a train en route from Station C to Station D the train will gather momentum as the distance is traversed and the maximum speed attainable at any point is shown by curve *H*.

Steps in Developing the Signaling

The signaling, however, cannot be located for this train speed for the reason that unless all trains are operated at this speed the specified headway cannot be maintained and as some trains may run at less than the maximum speed it is necessary to design the signaling system so that the specified headway can be maintained at the lower speed of operation and 17½ m.p.h. represented by curve *I* has been assumed as the lowest speed for which the signal system shall provide the specified headway.

While the train is proceeding over the route, time elapses and the time required for the train to accelerate to and proceed at a speed of 17½ m.p.h. is shown by curve *A*. This curve is developed from curve *I* by integration in small space intervals when the speed is constantly changing and for the full distance when the speed is constant. Thus, the train will consume 3.9 sec. traversing the first 20 ft. at the average speed of 3.5 m.p.h.; 2.96 sec. the next 20 ft. at the average speed of 6.75 m.p.h. and so on until the speed of 17½ m.p.h. is reached, after which curve *A* continues as a straight line representing the passage of the train at this uniform speed until the train reaches the point at which service braking is begun for the stop at Station D and the time consumed during this braking operation is determined in small increments as before. The time elapsing during the station stop when no distance is traversed is shown by curve *A* extended as a vertical line. We now have the position of the rear end of the train with respect to time and distance. A time-distance curve similar to curve *A* is not shown for the head end of this train because it is not essential to the design of signaling.

Curve *B* represents the head end of the following train starting out of Station C 90 sec. later and proceeding over the route as with the previous train. This following train may proceed according to curve *I* or it may run at maximum speed indicated by curve *H*. It is, therefore, necessary that the signals be so located that the following train will receive a stop signal at least braking distance from the rear end of the head train. The required braking distance, as previously stated, is proportional to the maximum speed at any point whatsoever and time distance curve *J* is drawn to show the point beyond which the following train must not pass at maximum speed, if braking distance plus a margin is to be provided.

The following train must not be allowed to pass into the braking distance zone at maximum speed, and from curve *J* it will be clear that with a train occupying Station D a train approaching at maximum speed must receive a stop indication not closer to Station D than Station 21 + 75.

Signal No. 2 is fixed at the exit end of Station C, being for this particular case the starting point of the signal system. Signal No. 2 is required to be at "Proceed," 2½ sec., before the following train is scheduled to pass it. In order for this to be obtained the next signal must be at "Caution," which requires that the preceding train must have passed out of the control of this "Caution" signal. The control of the "Caution" signal must extend at least braking distance beyond the next signal.

As stated in the specification, the time required for the operation of the signal equipment is 2½ sec. and therefore time-distance curve *K* is drawn 2½ sec. later in time relation to curve *A*. Also the time to be allowed for identification of a "Proceed" signal shall be 2½ sec. and accordingly time-distance curve *L* is drawn 2½ sec. earlier in time relation to curve *B*.

Spotting the Signal Location

The control limits of the "Caution" signal and consequently the clearing of No. 2 signal to "Proceed" is fixed by dropping an ordinate from the point of intersection of the abscissa representing 87½ sec. time with curve *K* to the distance scale at the bottom, as indicated by the light dotted lines *M* and *N* with the point of intersection at *O*. The control limit as thus found is at Station 19 + 85, as indicated.

The distance Station 2 to Station 19 + 85 is divided into three parts and the signal heretofore termed "Cau-

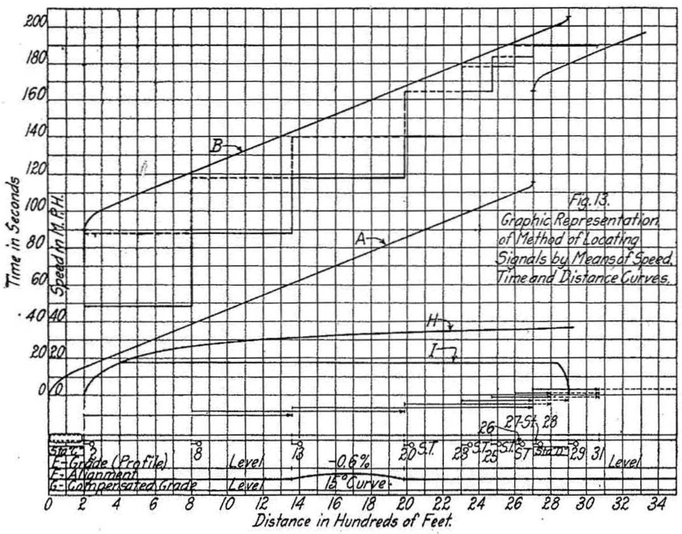

Fig. 13. Complete Working Curves

tion" becomes signal No. 8 located at Station 8 with its control extending at least braking distance plus a margin beyond signal No. 13, which has been located at Station 13 + 60. The reason for dividing the distance Station 2 to Station 19 + 85 into three parts is to provide one part for the overlap or braking distance zone, one part for the "Caution" block and one part for the "Proceed" block.

As shown on the figure, the rear end of the head train passes beyond the control of signal No. 8 85 sec. after leaving its starting point in Station C (that is, the headway of 90 sec., minus the 2½ sec. required for identification and minus the 2½ sec. allowed for the operation of the signal equipment), and 2½ sec. thereafter signal No. 8 clears to "Caution," which time is indicated by the point marked *P* and signal No. 2 clears to "Proceed" immediately thereafter. Similarly it can be shown signal No. 13 clears to "Caution" 2½ sec. after the head train stops at Station D and consequently signal No. 8 clears to "Proceed" as indicated by the point marked *Q*.

The dotted lines are merely visual guide lines to indicate the time of clearing to "Proceed" of the signal in the rear. The full lines are guide lines as before and also indicate in the diagram the amount of braking distance provided which, of course, is the distance from point *R* to point *Q*.

As will be observed, signal No. 13 cannot be cleared to "Proceed" because the control distance of signal No. 20 is occupied by the train at Station *D*. The only way by which signal No. 13 can be cleared to "Proceed" at the required time is to add one or more signals between signals Nos. 13 and 20 or shorten the control of signal No. 20.

The first alternative signal No. 13 could be made to indicate "Proceed" for a train approaching at the specified headway by virtue of the fact that the control of the additional signals need not extend into the station area because braking distance is available beyond signal No. 20. But even with this a train approaching at the specified headway would be stopped at signal No. 20 until such time as the preceding train had passed out of Station D and at least braking distance beyond signal No. 27 and the time of clearing to "Caution" for signal No. 20 is shown at *S*. This time is, of course, based on the preceding train moving in accordance with the specification and it will be clear that the specification cannot be met.

More Signals or Shorter Controls

The second alternative, that of shortening the control of signal No. 20, requires that the maximum speed be reduced in proportion to the necessary shortening of the control. So also signals will be required between signals Nos. 20 and 27 in order to provide suitable braking distance, which braking distance, of course, will be proportional to the restricted maximum speed.

Referring now to Fig. 12, curves *A, B, H, I, J, K* and *L*, together with signals Nos. 8, 13, 20 and 27 and time-clearing points *P* and *G*, bear the same relative significance as before.

The maximum speed at which a train may be permitted to approach an occupied station is dependent upon the braking distance which can be provided in the rear of the station train and to the extent that the maximum speed is not restricted to a figure less than the assumed operating speed of 17½ m.p.h. no obstacle will be introduced which will interfere with the maintenance of the specified headway.

It will be observed that the control of signal No. 20 now extends to cut-section No. 28 within the station limits and is occupied by the station train. In order that the control of signal No. 20 may be shortened enough to allow it to clear to "Caution" with a train in the station, a signal, for example No. 23, must be located between signals Nos. 20 and 27, which location must be braking distance plus a margin for the restricted maximum speed. On the clearing of signal No. 20, signal No. 13 will clear to "Proceed." That part of the control for signal No. 20 shown dotted is, in effect, shunted out by the closing of a time device contractor set in operation at the time an approaching train passes signal No. 8.

Time Spacing of Trains

This time device contactor is set to complete the shortened control of signal No. 20 provided the approaching train consumes an amount of time corresponding to 17½ m.p.h. average speed in No. 8 block; if so, signal No. 20 clears to "Caution" and signal No. 13 clears to "Proceed." If not, the operation of shortening the control of signal No. 20 is shifted to a similar time device contactor set in operation at the time an approaching train passes signal No. 13 and the train will receive a stop indication at signal No. 20 unless the train consumes an amount of time corresponding to 17½ m.p.h. average speed in No. 13 block.

The foregoing method of restricting the speed of a train in the approach to an occupied station is known as "two-block clearing" and is similar to the well-known method of controlling a normal danger signal system. It will be observed that the method provides for an approaching train to run on "Proceed" signals. Another method is to provide for the train to approach an occupied station on "Caution" signals, in which case it is termed "one block clearing." It will be noted that a train is restricted to a given average speed of transit over a definite distance. The longer this distance the more liberty may be taken by the motorman in running at an average speed; in fact, he may stop just inside the clearing section and stay long enough to complete the shortened control of a signal and then accelerate to pass a signal at a speed in excess of the average speed. This condition, of course, may be and is, prevented by making the clearing sections short either by introducing cut-sections or otherwise.

The respective long and short control limits are as shown and the respective times of clearing of the successive signals Nos. 23, 25, 26 and 27 are illustrated by points corresponding to points *P* and *Q* for signal No. 8.

With the addition of signals Nos. 23 and 25 and the necessary speed restricting devices it is possible for a train to move up to signal No. 25 before the preceding train starts out of Station D and by the further addition of signal No. 26 the train may begin to move up to signal No. 27 at the entrance to Station D as soon as the rear end of the preceding train has passed cut-section No. 28.

The dotted portions of the signal controls represent the braking distance required for the maximum attainable speed and are required for the protection of the preceding train during the time and distance required to move out of Station D after it once starts. The letters *ST*, shown adjacent to signals Nos. 20, 23, 25, 26 and 27, are merely plan characters used to indicate that under shortened control operation the speed of approach is restricted by the element time.

Final Analysis

Figure 13 showing the design just worked out is now shown again with all work lines and curves eliminated. The design has been worked out with every element involved receiving full consideration. The necessity for considering every element has been occasioned by the fact that of the 90 sec. headway, 50 sec., or more than one-half of the time between trains, is consumed by the station stop. This design has been worked out to show the degree of accuracy which can be attained in the scientific design of a signaling system and its influence on train operation.

The conditions of the foregoing specification are severe and require all the refinement which has been employed. Less exacting requirements would permit proportionately greater leeway in the refinement; indeed, it is easily conceivable that a certain amount of traffic can be provided for and protected without resort to factors other than time-distance curves based on average speed over large distances and, of course, with proper consideration for braking distance under the various conditions of grade.

Repairing the Maintainer's Car

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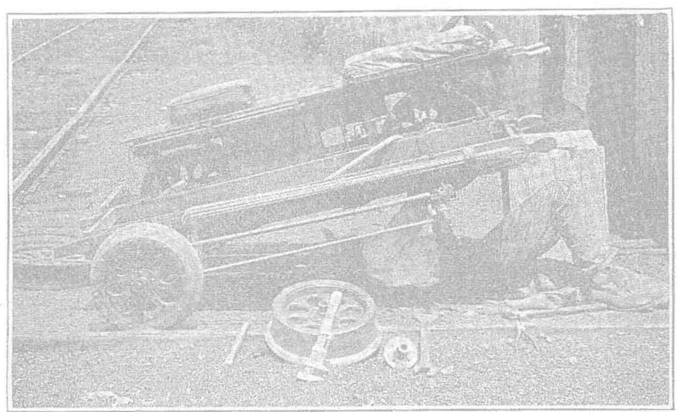
IN the preparation of this article the writer has endeavored to set forth the most important points entering into the operation and maintenance of the various classes of motor cars by contrasting experiences of those who *do* and those who *do not* repair the cars they operate. Of course, for the operator to make repairs he must receive instructions from those who are well posted on motor car operation and maintenance. This information may be furnished by the supervisor, motor car inspector or by a service engineer of a motor car company. Those using motor cars should be called to a meeting at least once a year to discuss car troubles and methods of prevention. If the maintainer knows his motor car he will get better service from it, repair parts will last longer, cost of repairing will be reduced and time will be saved.

In order to maintain a motor car in first-class operating condition one must know how the car is put together, therefore, the best way for a maintainer to become familiar with the working parts is to do the repair work himself. He will then learn the weak points and be able to handle any trouble that develops on the road.

Before the car is taken down for repairs the dispatcher should be given notice and also advised as soon as repairs have been completed in order to save delay in calling another maintainer in case of signal trouble. Many of the motor cars can be put in first-class running condition by two men in one day. Such work as painting can be done some Saturday or the day before a holiday.

Many signal maintainers have cars equipped with two cycle engines directly connected to the axle of the car. A cycle is one stroke of the piston regardless of the direction it moves. A two-cycle engine is one that has one power stroke to each two strokes of the piston, or to one revolution of the crank shaft. To make the operation of this type of gas engine clear compare it with yourself



A Few Hasty Repairs at Odd Moments

pumping a velocipede car. You are the pressure, the lever, the piston and the gear wheel is the crank. When you force the lever back you do the same thing as accomplished by the gas expansion against the piston. The lever goes back, you catch your breath to make another pull and similiarly the piston goes back, drawing another charge of gas into the firing chamber. When the lever