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Bulletin 156

Traffic Speed and Volume Measurements

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Contents

Measurement of Urban Traffic Congestion

CLAUDE A. ROTHROCK, Ohio Department of Highways, and
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This paper is an extension of one presented by Rothrock at the 33rd Annual Meeting of the Highway Research Board, entitled: "Urban Congestion Index Principles." It presents the results of a special study financed by the Yale Bureau of Highway Traffic, in which careful and precise measurements were obtained, during a period of 8 hours, of the progress of all vehicles in a lane of traffic through a test section subject to congestion.

Analysis and tabulation revealed certain characteristics which were developed into a concept of vehicle time-of-occupancy as a measurement of the degree of congestion. The basic concept is presented by a simple assumed example, and then applied to the data obtained on the test section. The possibility of developing a more practical and economical method of securing field measurements for general application is discussed.

● THE problem of the objective measurement of the degree of urban traffic congestion, and a method of comparing the measurements for different locations so as to obtain an index of relative degree of congestion, was the subject of a previous paper by Rothrock (1).

As a result of that paper, the Yale Bureau of Highway Traffic authorized and financed a field study by Rothrock to investigate the possible application of a concept for the evaluation of congestion expressed in terms of total vehicle time-of-occupancy for any given period. This concept is actually an application of the "operational-characteristics" concept, as it was termed and discussed in the 1954 paper.

During his attendance as a member of the 1955 class of the Yale Bureau of Highway Traffic, Keefer analyzed the data from the field study and applied the concept in a thesis (2), from which most of the material in the present paper is adopted.

Theory

The concept as developed may be simply expressed by a statement that traffic congestion consists of too many vehicles occupying space in a lane of highway for too long a time. This conception leads directly to the idea of total vehicle time-of-occupancy as an expression of the vehicular use of any given space of roadway for any given period of time.

The total vehicle time-of-occupancy will increase only directly as the volume of traffic increases, as long as there is no increase in the unit time-of-occupancy, or, stated differently, when any number of vehicles in traffic can move through a section of highway in the average optimum travel time, there is no congestion. From this it may be concluded that when the volume of vehicles composing traffic is so great as to impede their freedom of movement, and thereby increase the unit time-of-occupancy beyond the optimum travel time, there is congestion.

The degree of congestion for any such volume may be taken to be the amount by which the actual total vehicle time-of-occupancy exceeds what the vehicle time-of-occupancy would have been if the vehicles had been able to attain the optimum travel time.

To illustrate: Suppose a set of observations taken on a section of a single lane of road, considering travel in one direction only. Suppose that the driver of a vehicle, with due regard to speed limits, safety and prudent driving, can travel through this section in 10 seconds. Suppose also that during another similar period of observation, two such vehicles can each traverse the section in an average of 10 seconds, and suppose that during other periods of observation, up to six vehicles can each traverse the section in an average of 10 seconds. Arraying these observations by time period in the order of the vehicular volumes, the total vehicle time-of-occupancy for each is found to be as in Table 1.

TABLE 1

Number of Vehicles in Period	Average Time-of-Occupancy Per Vehicle (seconds)	Total Vehicle Time-of-Occupancy During Period (vehicle-seconds)
1	10	10
2	10	20
3	10	30
4	10	40
5	10	50
6	10	60

TABLE 2

Number of Vehicles in Period	Average Time-of-Occupancy Per Vehicle (seconds)	Total Vehicle Time-of-Occupancy During Period (vehicle-seconds)
7	11 5	80
8	13 5	108
9	16 0	144
10	19 0	190
11	23 0	253
12	28 0	336

Because the average time-of-occupancy is constant, there has been no vehicular delay, and plotting the data with the volume (number of vehicles) as abscissa and the total vehicle time-of-occupancy as ordinate results in a straight line as shown in Figure 1.

Now suppose further that during another period of observation seven vehicles traversed the section with the effect that the average time-of-occupancy for each was increased from 10 seconds to 11.5 seconds, and that during similar periods of observation the volume of traffic increased to the extent that the average times-of-occupancy were correspondingly increased, approximately as shown in Table 2. These data also have been plotted in Figure 1. This, of course, is a "manufactured" and somewhat exaggerated case, devised solely for the purpose of illustrating the theory of this one method of congestion measurement.

Referring to Figure 1 again, a dotted line has been extended to the right from the straight line representing the data from Table 1. This straight line is what would have been obtained if the average time-of-occupancy for the 57 vehicles represented in Table 2 had remained at the optimum of 10 seconds, in which case there would have been no congestion.

The concept of excess vehicle time-of-occupancy as an indication of congestion, aside from its use in calculating an index, is a useful value for direct comparison, as it is actually the measurement of time lost by vehicles due to congestion. Thus a value per vehicle-minute can be placed upon it and the cost of congestion readily computed. It may even be practicable to estimate an annual congestion loss for a given space of highway by the application of appropriate traffic factors.

Application

The calculation of the vehicle time-of-occupancy is not difficult. There are at least two relatively simple ways of obtaining it, as follows:

1. For the given section of street during any time period of observation, say for the peak hour, the vehicle time-of-occupancy is simply the average density multiplied by the time of observation. If instantaneous counts of density could be made during the hour frequently enough to get a true average of density (that is, the number of vehicles in the section at any instant) the vehicle time-of-occupancy would be the average density multiplied by the length of the period of observation or, where the period of observation is an hour, the average density is the same as the vehicle time-of-occupancy expressed in terms of vehicle-hours. To be expressed in minutes, the average density would be multiplied by 60.

2. For any section of street during any time period of observation, say for the peak hour, the vehicle time-of-occupancy is simply the volume count of vehicles entering the section multiplied by the average travel

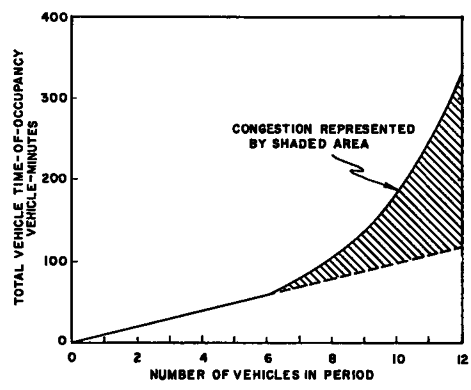

Figure 1. Hypothetical vehicle times-of-occupancy during congested and uncongested time periods of observation.

time through the section for those vehicles, as may be obtained by test car runs during the period. In this method the count of vehicles is not an instantaneous one of density, but a continuing count of volumes.

To illustrate how the foregoing calculations might be made for a selected sample: Suppose observations are made during the peak hour on a section of street with one travel lane in each direction, with observations confined to a single lane, the direction of which is toward a traffic-signalized intersection at one end. Suppose the length of the section to be three blocks between ends, totaling 1,200 feet, the beginning and intermediate intersections not being signalized.

At times during the observations, made during the peak hour, it is probable that the lane would be completely filled with cars queued up, especially during the red phase of the signal. At other times it is also probable that the lane will contain freely moving vehicles, especially during the latter seconds of the green phase of the signal.

Suppose a series of instantaneous counts of the number of vehicles in the lane be made, such as might be taken from a series of instantaneous photographs, so spaced in time that the average of the counts gives a true average density. Suppose this average is found to be, say 25 vehicles. Then, from the foregoing, the total vehicle time-of-occupancy is found to be 25 vehicle-hours, or 25 by 60 = 1,500 vehicle-minutes.

Now suppose that during the same hour of observation, time and delay runs had been made with a test car, with sufficient number and spacing to give a reasonably accurate average of the travel times through the section, including necessary stops, for all the the vehicles entering. Suppose also that a volume count had been made of all vehicles entering the section.

Assuming that the test runs give a calculated average travel time of 2.7 minutes, and that the volume count is 570 vehicles per hour, the value for the vehicle time-of-occupancy is obtained by multiplying 570 vehicles times 2.7 minutes, or 1,539 vehicle-minutes; practically the same value as that obtained by the previous method.

If the purpose of the observations is to obtain a concrete measurement of congestion they must be made for the predetermined times for which the congestion is to be assessed. Probably the peak hour of travel (or hour of most congestion) would be the most useful period, because designs for capacity are generally based on volumes for that time.

Having an expression for the vehicle time-of-occupancy during the peak hour, a comparison may be made with what may be termed the normal vehicle time-of-occupancy, during an off-peak hour of uncongested traffic. This may be the maximum such figure obtainable during an hour when the average travel time per vehicle is not in excess of that to be found at any time for free moving vehicles.

In the foregoing case, this may be assumed to be during the maximum volumes of traffic counted at the signal when no vehicles are necessarily stopped by more than one red phase of the signal cycle. If the cycle is 50 seconds, for instance, of which the red phase is 25 seconds against traffic in the lane under consideration, the probable maximum volume which could pass without undue hindrance would be 8 vehicles per cycle, which could conceivably account for 600 vehicles per hour.

In any continuous hour, however, it is not probable that an average frequency in one lane of 1 vehicle per 3 seconds of green could be maintained without some periods of congestion, due to the uneven spacing and speeds of vehicles.

Suppose that it had been found by tests under the conditions here assumed, with an allowable speed of 25 mph, that the largest volumes of traffic that did pass such a signal without restriction of movement except from the signal was approximately 275 vehicles per hour. This volume was passed at an average running time of 47 seconds, which accounts for an average speed of about 20 mph. This condition, for the purpose of discussion, will be here assumed as the optimum criteria by which to compare the vehicle time-of-occupancy figures.

If it should be found that the average travel time for vehicles under volumes less than 275 vehicles per hour is maintained at approximately the same average travel time (that is, 47 seconds), and that at volumes greater than this the average travel time increases substantially above 47 seconds, the 215 vehicle-minutes of occupancy may be assumed to be the optimum normal.

On this assumption there is one method of comparison available by which it may be said that the congestion during the peak hour of travel amounts to the vehicle time-of-occupancy during the peak hour, less the vehicle time-of-occupancy during the optimum hour, or 1,539 - 215 = 1,324 vehicle-minutes. This could be expressed as a ratio, or $\frac{1,539}{215}$ = 7.16, which may thus be considered as one way of expressing an index of the relative congestion per lane, per given section of street.

It is possible, however, that both of these values, the one for the index and the one for the amount of congestion, may be false or misleading.

In the first place the optimum, or standard of comparison, might be taken as the time-of-occupancy calculated for the volume of traffic found to be the practical capacity. If this is established, the question remains as to what value to use for the average travel time through the section.

It would be difficult to find an hour during which the traffic volume was almost exactly the practical capacity and in which there would not be some sort of deviation from the average spacings and speeds. Perhaps a series of short time counts and travel time runs, say for intervals of 6 minutes, could be obtained and the average travel time of several most nearly equal to 1/10 the volume of practical capacity taken as the optimum travel time. In the following example 400 vehicles per hour is assumed as the volume representing practical capacity.

Now suppose that the average time during such counts turned out to be 47 seconds, as before. The index found by comparing the peak hour time-of-occupancy with the time-of-occupancy computed by multiplying the practical capacity by the optimum average travel time would be 400 by 47 seconds = 312 vehicle-minutes, and the index would be $\frac{1,539}{312}$ = 4.93. The amount of congestion would be 1,539-312 = 1,227 vehicle-minutes.

Then again it may be argued that the optimum should be taken as the volume during the peak hour multiplied by the average travel time for the hour of best conditions of travel. In this case, with a constant volume, the difference between the two times-of-occupancy would amount to time lost by those vehicles.

In such a situation, assume the values used in the previous examples: Peak hour volume = 570 vehicles; average travel time during the peak hour = 2.7 minutes; and average travel time during the optimum hour (hour of best travel conditions) = 0.78 minute. Then for the peak hour the time-of-occupancy = 570 by 2.7 = 1,539 vehicle-minutes, and for the optimum (or standard) the time-of-occupancy = 570 by 0.78 = 445 vehicle-minutes. A measurement of the amount of congestion would be 1,539-445 = 1,094 vehicle-minutes which, of course, would be the same as 570 (2.70-0.78) = 570 by 1.92 = 1,094 vehicle-minutes.

Then the index of congestion would become $\frac{1,539}{445}$ = 3.46.

It is also possible that a "double-barreled" index, showing a comparison with both the practical capacity and the maximum capacity as previously shown would be desirable. A statement that the index of congestion for the section equals 3.46 at the peak hour and 4.93 at practical capacity may be more revealing than a statement of either separately.

It would be necessary, to be able to express the amount of congestion in accord with some predetermined common denominators; that is, it should be expressed as representing the level of congestion per traffic lane per mile or per 1/10 mile. The latter value is particularly useful because it approximates the average urban block length. This step would be necessary to facilitate the comparison of congestion for two or more street sections of different length or number of lanes.

For example, the numbers previously shown represent the amount of congestion for a single traffic lane 1,200 feet long. Inasmuch as 1 mile is 4.4 times 1,200 feet, the values might be stated as 1,227 by 4.4 = 5,399 vehicle-minutes per lane per mile, and 1,094 by 4.4 = 4,814 vehicle-minutes per lane per mile. This would allow a relative comparison with another congested section of different length, whereas with the original index figures the comparison is quantitive, not relative.

The observations in the preceding examples could be expanded in length of section and traffic to cover the traffic on multi-lane streets in both directions, so as to cover the total traffic on any length of section. Normally, the congestion quantity would be obtained for all lanes in both directions for a given section or area, for practical evaluation purposes. Single-lane, one-directional observations were used in the foregoing simply to illustrate the hypothesis.

An area or an intersection would be evaluated by as many counts as necessary on the various legs that contribute to congestion, the various units of occupancy being added together to produce a complete picture without overlap or gaps. This might be termed a "cordon" count technique applied to the measurement of urban traffic congestion. Theoretically, the technique could be expanded to cover almost any area. The method is illustrated in Figure 2.

It is manifest that an index figure does not mean much quantitatively unless the total extent of each case of congestion is known for comparison. For example, an index of 3.46 at one location as compared to an index of 3.46 at another does not mean that they are equal in amount of congestion, because one case may cover only a short distance and the other a much greater distance. If the indexes are intended to denote which of the two cases should be given priority in remedial treatment, no choice is indicated, whereas the case having the greater length should be treated first. The cordon count technique can settle this problem by obtaining the quantity as well as the quality of congestion.

METHOD OF STUDY

When this study was first contemplated, it was decided to confine the field work to a simple type of problem, that of an ordinary two-lane urban street, with parking permitted and travel in each direction. It is probable that a large proportion of existing congestion is found on streets of this type.

Test Section

A section of street in an intermediate urban area of Charleston, W. Va., was chosen as an almost ideal situation, affording in one continuous stretch several different conditions needing appraisal. The street was approximately 40 feet wide throughout the section. It consisted of two lanes of moving traffic, one in each direction, with parking permitted on both sides except at variously-located bus loading zones. The annual average daily traffic of 12,000 vehicles included a large percentage of trucks and busses.

It was decided to break the subject of study into small section units for separate observation, and to define the limits of each in such a way that it would logically remain an integral unit, the characteristics of which could be combined with those of other similarly defined units to add up to the characteristics of the whole facility without overlapping or omission. The total section length of 1,200 feet was therefore divided into four more or less equal segments, with breaks at the two intermediate intersections and at one mid-block location.

The dividing lines between sections were called cordon count lines. These lines were extended across the western or far sides of intersections and across side streets as continuations of curb lines. Subsequent counts were thus made of vehicles as they cleared the intersections or count lines.

A count station was established near each cordon count line, as shown in Figure 3. The five count stations were lettered consecutively from the initial station to the final station, the latter being located at an isolated, signalized intersection.

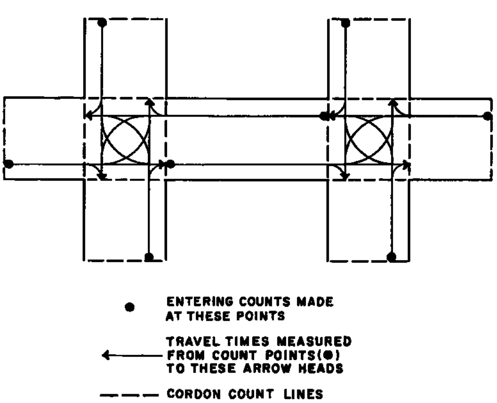

Figure 2. Cordon count concept applied to the measurement of urban traffic congestion.

Field Work

The field work consisted primarily of obtaining a detailed record of the times re-

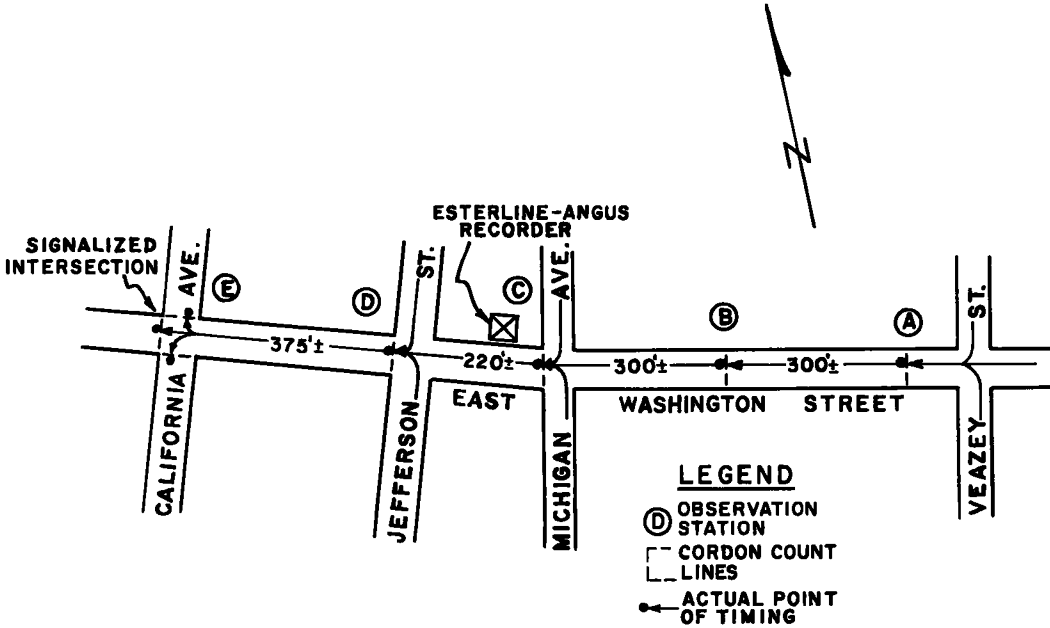

Figure 3. Schematic drawing of the test section.

quired for all westbound vehicles to travel through the section. Records were made of the single westbound lane of traffic from the time that it entered the section at Station A until it left at Station E.

The times were recorded on an Esterline-Angus recorder tape by means of an electrical circuit operated by telegraph contact keys. In addition to recording the times of vehicles entering or leaving the terminal stations, the times that they passed through the intermediate stations were also recorded; at two of these latter, the times of those vehicles entering from the side streets were recorded. To facilitate identification of individual vehicles, the type and last three digits of the license plate number of each vehicle was recorded as it cleared each station.

Details of the operation to be performed by each field worker were explained previous to the days of observation. The number and kind of worker required for each station was as follows: Stations A and B required one key operator, one recorder, and one relief man each; Stations C and D each required one key operator, two recorders, and one relief man; Station E required one key operator, two recorders, one observer, and one relief man. Another man was needed at the recorder to insure its proper functioning at all times. Two general supervisors were active throughout the section.

The observations began at 2:00 P.M., May 21, 1954, and ended at 7:00 P.M. Observations were continued the following day from 7:00 to 11:00 A.M. All the work was done in good weather with no unusual conditions to interfere with the established traffic pattern in the section.

In addition to the observations, a series of time and delay runs was scheduled so that the average travel times could be compared as between the test car and all vehicles. A single test car, with the same driver and observer throughout, made as many runs as practicable each hour through the total section. The "average" car technique was used throughout.

The data collected in the field consisted of several hundred field sheets and three lengthy Esterline-Angus recorder tapes. The initial step in analyzing the data was to match the partial license numbers noted on the field sheets by the recorders to the appropriate "blips" actuated on the tapes by the key operators. Where occasional error in telegraph key operation or license number recording occurred, matching was made difficult but not impossible.

After matching license numbers had been transcribed on the corresponding tapes, it was comparatively simple to follow the course of any given vehicle through the section and to compute its exact travel time from any station to the next in minutes and hundredths of minutes.

The mass of information represented by the completed tapes was then coded and business machine cards were punched, sorted, and tabulated. The final tabulation showed the number and classification of all vehicles entering the test section, and the total times-of-occupancy in the section as well as in each of the subsections, by 6-minute intervals.

ANALYSIS OF DATA

The nature and location of the section selected for the study were such that most of the vehicles recorded entered at the initial station and continued through to the final station. These vehicle trips, termed "through," numbered 4,301 vehicles, or 92 percent of all the vehicles recorded in the section during the observation period.

However, some of the vehicles recorded entered or left the section at the intermediate stations. These vehicle trips, termed "intermediate," numbered 377 vehicles, or the remaining 8 percent of all vehicles recorded in the section during the observation period. Extensive analysis indicates that intermediate trips can be ignored in this presentation without significant loss of detail.

Westbound vehicles entering the section at the initial station followed the typical pattern for an intermediate urban location. Hourly volumes increased rapidly during the morning, with peak arrival periods around 9:00 and 10:30 A.M. Hourly volumes were relatively constant during the afternoon, with peak arrival periods around 3:30 and 4:30 P.M. The highest hour of traffic was 4 to 5 P.M., with 627 entering vehicles. The second highest hour of traffic was 3 to 4 P.M., with 579 entering vehicles.

All vehicles were classified into five convenient groups, as follows:

1. Passenger cars, including panel, pickup, and single-tire trucks.
2. Dual-tire vehicles.
3. Combination vehicles.
4. Busses.
5. Test car.

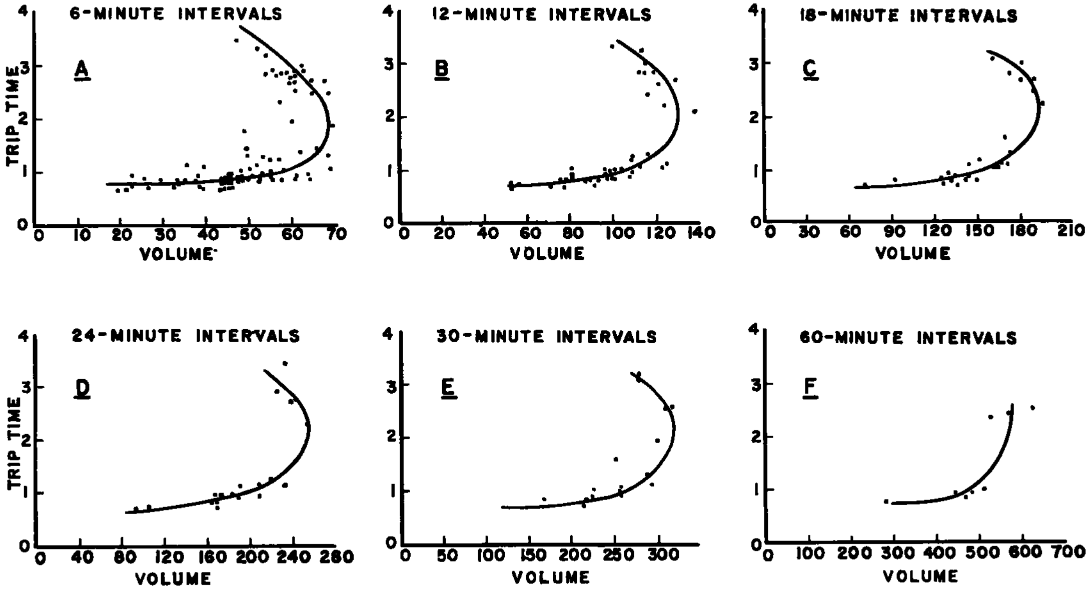

Figure 4. Relation of entering volumes to average trip times-minutes.

Average Travel Times

The average travel time was simply the average time that was required by a given number of vehicles to travel from Station A through Station E of the test section. The average travel times were computed for through trips only, by 6-, 12-, 18-, 24-, 30-, and 60-minute intervals. For the 60-minute interval between 4:00 and 5:00 P.M., for example, the 592 vehicles which passed through the section required an average travel time of 2.56 minutes each.

Travel times for individual vehicles varied greatly. One vehicle was recorded through the section in the minimum time of 0.40 minute, corresponding to an over-all speed of about 34 mph. Another was recorded through the section in the maximum time of 4.90 minutes, corresponding to an over-all speed of about 3 mph, or as slow as a brisk walk.

The average travel times also varied greatly, but not through such a wide range. In general, the average travel times were lowest when the section was experiencing a light volume of traffic, and highest when experiencing a heavy volume of traffic. It is important to note that this function was actually reversed at or near the point of critical density as defined in the "Highway Capacity Manual" (3). At that point, while the recorded volume of traffic decreased abruptly because of congestion and stoppages, the average travel times continued to increase. This is well illustrated in Figure 4.

Good correlation was obtained between the all-vehicle and the test car average travel times. The greatest deviation of average travel times occurred during the hour 7 to 8 A.M. It seems probable that the test car driver at that time may have passed too many vehicles to conform to the "average car" technique, with more frequent opportunities due to lack of opposing traffic. With the exception of that hour, the test car average travel times were within ± 7 percent of the average travel times for all vehicles, on an hourly basis. Computed on a 6-minute basis, the coefficient of correlation was found to be 0.9679.

These results compare favorably with those obtained in a similar study on a 1.45-mile section of urban street in California. Berry (4) stated that on all but one of the test sections, both average and floating test runs yielded mean values within 7 percent of the means obtained by the license-check method. He further concluded that to obtain an accuracy of 10 percent, 8 and 10 test car runs per hour would be needed on two-lane urban uncongested and congested routes, respectively.

The somewhat better results obtained in this study with an average of nine test car runs per hour and using the same "average car" technique, may be due to the relative brevity and substantially uniform conditions of the 1,200-foot test section. Both studies produced test car travel times which were lower than those of the license-check method.

Relation of Average Travel Times to Entering Volumes

The average travel times for all vehicles have been plotted (Figure 4) against the volume of traffic entering the section of the initial station for the corresponding time intervals of 6, 12, 18, 24, 30, and 60 minutes, as a family of scatter diagrams. In each, entering volumes are the abscissas and average travel times are the ordinates. For ease of comparison, scales were made proportionate to the various time intervals represented.

The superimposed curves, which were fitted by visual effect, tend to turn back on themselves. The 12- and 18-minute interval curves (B and C) seem to show the effect best. For example, although many 12-minute intervals reveal an average travel time of about 1 minute, several others with approximately the same entering volumes show an average travel time of about 3 minutes. This could be taken as one simple indication of the amount of congestion present during the latter intervals.

The effect is not entirely unexpected. Greenshields (5) has discussed its theoretical aspects in his recent publication dealing with highway traffic analyses. Although his analysis deals with speed rather than time, the curves presented are quite similar to those in Figure 4.

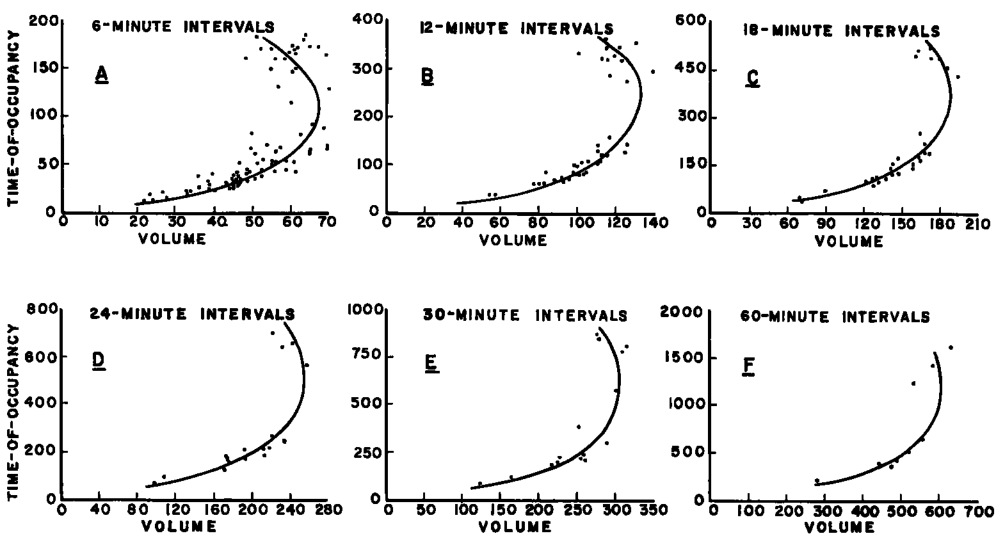

Figure 5. Relation of entering volumes to time-of-occupancy minutes.

Vehicle Times-of-Occupancy

As previously defined, the vehicle time-of-occupancy during a given time period was simply the average density multiplied by the time of observation. From the recorder tapes, vehicle densities were computed at 1-minute intervals for the hour 4 to 5 P.M. Average density in the test section for that hour was found to be 25.5 vehicles. Total time-of-occupancy = 25.5 by 60 minutes (period)of observation) or 1,530 vehicle-minutes. Although this method is relatively simple in itself, it is recognized that more convenient ways may be found to use the average densities concept in obtaining total time-of-occupancy. Greenshields has suggested three ways: a photographic method, an adaptation of the Esterline-Angus recorder method, and a calculating machine method.

Also as previously defined, the vehicle time-of-occupancy during a given time period was simply the volume count of vehicles entering the test section multiplied by their average travel time through the section. The total entering through volume for the hour 4 to 5 P.M. was 592 vehicles. The average travel time for all vehicles during the hour was 2.56 minutes.

In this example, total time-of-occupancy = 592 by 2.56 = 1,516 vehicle-minutes. That compares well with the 1,530 vehicle-minutes obtained from the average densities computation. The present method makes use of the travel time observations recorded on the Esterline-Angus tapes and, therefore, is assumed to be most accurate.

If the test car average travel time is substituted for the all-vehicle average travel time during the same time period, still another measure of the total time-of-occupancy is found. Again illustrating with the peak hour 4 to 5 P.M., with total entering volume the same as before, total time-of-occupancy = 592 by 2.62 = 1,551 vehicle-minutes.

The total vehicle time-of-occupancy as determined from the Esterline-Angus tapes increased rapidly from the morning to the afternoon hours of observation. This was expected, because time-of-occupancy is the product of entering volumes and average travel times, both of which values also increased from morning to afternoon hours.

Relation of Time-of-Occupancy to Entering Volumes

The total times-of-occupancy for all vehicles have been plotted against the volume of traffic entering the section at the initial station, for corresponding time intervals of 6, 12, 18, 24, 30, and 60 minutes, as a family of scatter diagrams (Figure 5). In each, entering volumes are the abscissas and total times-of-occupancy are the ordinates. Scales were again made proportionate to the various time intervals represented for ease of comparison.

The superimposed curves are fitted by visual effect rather than by formulas. As with the family of curves in Figure 4, these tend to turn back on themselves. Thus, the highest entering volumes do not assure the greatest total time-of-occupancy.

Not unexpected, the cause of this phenomenon is largely self-explanatory. As entering volumes increased to the point of critical density, the total time-of-occupancy increased more or less linearly. When that point was reached, the greater delay allowed fewer entering vehicles, but required longer travel times, which resulted in greater over-all time-of-occupancy. It is obvious that the travel times increased at a more rapid rate than the entering volumes decreased.

Congestion Indexes

It was found during the field work that when entering volumes were 282 vehicles per hour, or less, the average travel time for all vehicles was maintained at approximately 0.78 minutes. At volumes greater than this, the average travel time increased substantially above 0.78 minutes. In deriving the Simple Index, the optimum normal time-of-occupancy may be assumed to be 282 by 0.78 = 219 vehicle-minutes.

The actual time-of-occupancy for any given hour of the field work can be taken directly from the travel time observations as recorded on the Esterline-Angus tapes. For the peak hour of 4 to 5 P.M., the actual time-of-occupancy was 1,516 vehicle-minutes. During the peak hour, then, congestion amounted to the vehicle time-of-occupancy recorded for that hour, less the vehicle time-of-occupancy represented by the optimum hour; 1,516-219 = 1,297 vehicle-minutes. This can be expressed as a ratio, $\frac{1,516}{219}$ = 6.92, which may be considered as one way of expressing an index of the relative congestion existing in the single westbound lane of the test section.

The optimum normal time-of-occupancy may also be taken as the time-of-occupancy obtained with the volume of traffic found to be the practical capacity of the test section. In this case, the signalized intersection at Station E was the limiting factor which determined the practical capacity for the entire section.

Using the procedure outlined in the "Highway Capacity Manual" (3), the practical capacity of the intersection was found to be approximately 400 vehicles per hour. Unfortunately, in no single hour of the field work was the traffic volume even roughly equal to 400 vehicles per hour. To overcome this obstacle, the average travel time of several 6-minute intervals most nearly equal to 1/10 of the volume of practical capacity was taken as the optimum travel time.

The average travel time thus arrived at was 0.78 minutes, exactly the same as for the hour previously used for an optimum in which the volume was 282 vehicles per hour. Using this value as the optimum travel time, the optimum normal time-of-occupancy at the practical capacity would be 400 by 0.78 = 312 vehicle-minutes. The index of congestion found by comparing the peak hour actual time-of-occupancy, say, with the optimum time-of-occupancy at the practical capacity would be $\frac{1,516}{312}$ = 4.86.

The optimum normal time-of-occupancy may also be taken as the volume during the peak hour multiplied by the average travel time for the hour of best conditions of travel. The optimum normal time-of-occupancy at the peak hour would thus be 592 by 0.78 = 462 vehicle-minutes. The index of congestion found by comparing the actual peak hour time-of-occupancy with the optimum peak hour time-of-occupancy would be $\frac{1,516}{462}$ = 3.28.

Comparison of the Three Types of Indexes

The same optimum travel time of 0.78 minute was used in the calculation of each of the three indexes. For the Practical Capacity Index, the optimum travel time was the same as for the other indexes, apparently as a matter of chance. It is suspected that future applications of the Practical Capacity Index will find the optimum travel time somewhat higher than for the Simple or Peak Hour Index. The optimum travel time corresponded to an over-all speed through the test section of 17.4 mph.

It has been suggested that the optimum travel time be based on the legal speed limit

(25 mph in the test section). This possibility was rejected on the grounds that (a) the legal speed may be so slow as to impede movement itself, or (b) so high as to be unattainable. In either case, false indications of congestion would appear in the calculation of any index.

It has also been suggested that some constant speed, say 35 mph, might be selected arbitrarily to represent completely satisfactory travel time conditions for urban areas. This concept might even be expanded in use to provide for different desirable speeds in downtown, intermediate, or residential areas. Further research should be devoted to this possibility.

For each index, the same optimum travel time was applied against a different volume level. For the Simple Index, it was applied to the volume above which it could not be obtained (282). This produced the least optimum normal time-of-occupancy and the highest numbers of the three types of indexes.

Making use of a somewhat higher volume level (400), the Practical Capacity Index had a higher optimum normal time-of-occupancy and consequently lower index numbers. Applying the optimum travel time against a still higher volume level (592), the Peak Hour Index had the highest optimum normal time-of-occupancy and the lowest index numbers of the three types of indexes.

The three indexes previously calculated are for the total test section. They could as well have been calculated for any of the subsections merely by substituting whatever optimum travel time was found to be applicable for each, and proceeding according to the method used for the entire section.

Eventually, of course, the congestion quantity would be obtained for all lanes in both directions for a given street section or area by use of the cordon count technique described earlier. This would be possible with any one of the three indexes, because they each possess the property of "additiveness".

Excess Time-of-Occupancy as a Measure of Congestion

As previously stated, the concept of excess vehicle time-of-occupancy as an indication of congestion, aside from its use in calculating an index, is a useful value for direct comparison, as it is actually the measurement of time lost by vehicles due to congestion. The cost of congestion occurring in a given section of street during a given interval of time can be readily computed by placing a value per vehicle-minute upon such lost time.

To illustrate: Using the Simple Index, the excess vehicle time-of-occupancy during the peak hour 4 to 5 P.M. in the test section was 1,297 vehicle-minutes. Placing a value of $0.02 per vehicle-minute upon it, the monetary loss for the single hour was $25.94. Losses due to congestion can be similarly computed for all the hours of the field work during which congestion actually occurred.

SUMMARY AND CONCLUSIONS

The study began with the development of this definition of congestion: "The condition in which traffic, because of impedences from any source, moves at average over-all speeds less than the maximum speed that is tolerable, considering prudence and safety."

From this, the concept of excess vehicle time-of-occupancy as one indication or measurement of congestion was evolved. To illustrate the concept, observations and comparisons were made of the actual and optimum vehicle times-of-occupancy in a selected test section under varying volume conditions.

It was found that the actual total time-of-occupancy in the section increased only directly as the total entering volumes increased, up to the point at which congestion may be said to have begun. Thereafter, as the average vehicular travel times increased because of various impedances, the actual time-of-occupancy increased faster than the entering volumes. As congestion became even more severe, the time-of-occupancy continued to increase while entering volumes remained constant or decreased slightly.

Time and delay runs were made through the test section to determine if the average travel times recorded by the test car could be used to represent the average travel times recorded by all vehicles. A positive answer was found in the resulting coefficient of correlation of 0.9679.

The least obtainable travel time through the test section during one continuous hour, without restriction of movement except from the signalized intersection at Station E, was 47 seconds. This was possible with entering volumes up to 282 vehicles per hour; with greater volumes the average travel time increased substantially above 47 seconds.

The least obtainable travel time was then applied to three magnitudes of entering volumes to produce three optimum times-of-occupancy. In the first case, it was applied to that volume above which it could not be obtained; in the second, to that volume which represented the practical capacity of the signalized intersection at Station E; in the third, to the observed volume in the test section during the peak hour.

The formulas for each of the three congestion indexes developed in this study are based on the ratio of actual to optimum time-of-occupancy. The major formula is:

$$\text{Congestion Index Number} = \frac{\text{Actual Time-of-Occupancy}}{\text{Optimum Time-of-Occupancy}}.$$

In the calculation of an index, the actual occupancy value is as observed in any given space of roadway. The optimum occupancy value may vary, depending on the type of index selected for use.

Assuming equivalent entering volumes, it is evident that the time-of-occupancy required in the test section during periods of congestion, exceeding that required during periods of no congestion, is a direct measurement of lost time by vehicles due to congestion. A value per vehicle-minute can be assigned to it, and the cost of congestion readily computed. It may even be practicable to estimate an annual congestion loss for a given space of roadway by the application of appropriate traffic factors.

It may be possible that under some circumstances the excess time-of-occupancy would be a more revealing measure of congestion than an index number. It is recommended that both measurements be given proper consideration in the evaluation of congested highways.

It should be acknowledged that further research may well uncover a better measurement of congestion. Greenshields (6) has proposed a method of measuring the quality of traffic transmission in urban areas. Conradt (7) has developed a "service rating" for urban streets. Other urban rating scales have been used for many years. Although these have not been ignored, it is felt that the present study offers a method of measuring urban congestion that may have general application until such time as better measures are introduced.

Before embarking on any comprehensive program involving the measurement of urban traffic congestion, various unsolved questions must be resolved. Having proved that the test car method of obtaining time-of-occupancy is valid, thereby assuring future savings in time and money over that method used in this study, there remains to be found for practical uses an even faster and cheaper method.

Experience in usage may be necessary to determine which of the three indexes developed are best suited to particular locations; perhaps different type indexes would be required for different types of urban streets. There may be reason to believe that the Simple Index would be best used on non-signalized sections, for example, while the Practical Capacity Index, because it recognizes a certain delay from adverse signal indications, would be better for signalized sections.

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Moving Vehicle Method of Estimating Traffic Volumes and Speeds[1]

WILLIAM J. MORTIMER, Superintendent of Highways
Cook County, Illinois

The two most commonly used methods for obtaining traffic volumes are the machine count and the manual count at fixed locations or stations, and for a number of hours duration. These methods are expensive and time-consuming.

Many attempts have been made in the past to develop sampling techniques whereby the total volume of traffic could be estimated by sampling only a relatively small portion of the total traffic flow. One such technique was recently developed in England by Wardrop and Charlesworth and reported under "A Method of Estimating Speed and Flow of Traffic from a Moving Vehicle." The Cook County Highway Department investigated this technique to test its usefulness in this country, considering only the estimation of the flow of traffic.

If a large number of sections are to be sampled, with the idea of estimating the total combined volume of all sections, the method appears to be very useful, for while in any single section there may be a sizeable error, these errors appear to cancel out when sections are combined. If a fixed degree of precision is required on all sections, the sampling time will vary inversely with the volume in question.

It appears, at present, that for estimating total traffic volume flow or total vehicle miles driven, this method is the fastest and may well be the most economical. Studies are underway to compare the cost of this method with other known and accepted methods.

● TECHNIQUES in traffic engineering are constantly being improved. Each such improvement adds to the collection of tools for establishing sound highway programs. No new technique is of real value unless it features significant advantages over the old.

Traffic volumes for use in highway planning are obviously important. To realize such information quickly and economically is of equal importance.

The moving car method is offered as a means for estimating traffic volumes and speeds quickly, economically and accurately.

DESCRIPTION OF METHOD

The main objective of this study is to test the feasibility of a method of estimating traffic volumes on urban streets by use of extremely short counts taken from a moving vehicle. This study is an extension of work first done by John Wardrop and George Charlesworth and presented before the Institution of Civil Engineers, London, England.

The moving car method under study here, requires the use of a car, a driver, and one or more observers. The number of observers is dependent upon the details sought. In this study it was found that one observer was sufficient, as no breakdown of vehicular types was attempted. Figure 1 illustrates the method.

In this method, as the moving car unit "U" travels a sector of highway under study, the observer records the stop watch time required to drive the section, the vehicles "M" moving in the opposite direction and met by the moving car unit, the vehicles "O" overtaking the moving car unit, and the vehicles "P" passed by this moving car unit.

These observations are the basis for the estimates of traffic volumes and velocities of the highway section traversed.

FIELD TECHNIQUES

Included in this study were ten road sections described in the table entitled, "Description of Sections."

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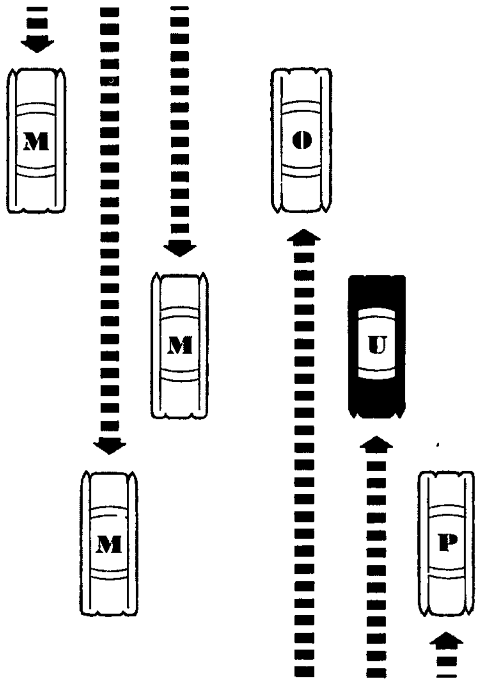

Figure 1.

The spatial relationships of the sections to one another are illustrated in Figure 2.

In selecting this network of sections, an attempt was made to include a variety of road types containing a significant difference in traffic volumes and land use.

Figure 2 shows all of the field elements required to conduct this study, namely study travel path, the relative paths of the two

DESCRIPTION OF SECTIONS

	Length in Miles	Average Driving Time in Minutes	Average 5 Hour Volume	Land Use	Highway Type	Through Street (T) Not Through (N T)
(1)	55	1 2	2622	Residential	4 Lane Divided	T
(2)	50	1 1	3381	Residential	4 Lane Divided	T
(3)	50	1 2	3720	Residential	4 Lane Divided	T
(4)	65	1 9	4491	Business	4 Lane	T
(5)	50	1 4	241	Residential	2 Lane	N T
(6)	50	1 4	292	Residential	2 Lane	N T
(7)	50	1 4	2329	Residential & Business	2 Lane	T
(8)	50	1 2	2272	Residential & Business	4 Lane	T
(9)	50	1 2	2372	Residential & Business	4 Lane	T
(10)	55	1 4	297	Residential	2 Lane	N T

STUDY AREA DIAGRAM

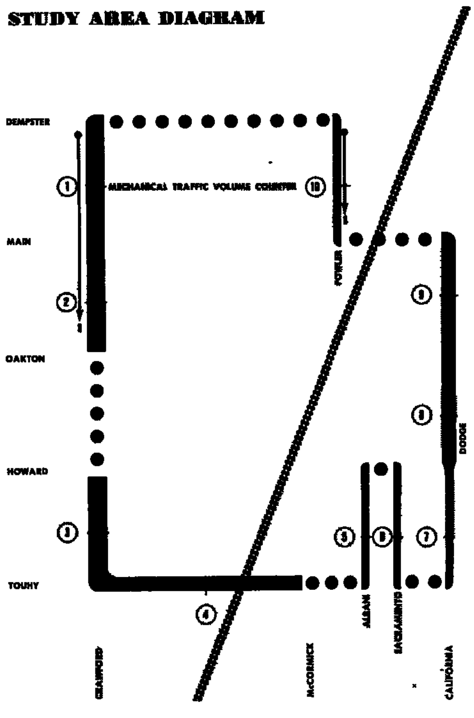

Figure 2.

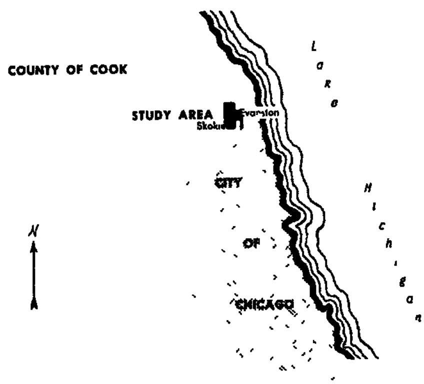

Figure 3. Area location map

vehicles used, and the location of the mechanical traffic volume counters. Speed meter locations used for this study are not shown in Figure 2. The paths of the two vehicles shown in Figure 2 were designed to reduce the errors which could arise from sampling uni-directional travel

Each car contained a driver and one recorder.[2] As the car entered a section, the recorder actuated the stop watch and began the count of: (1) the oncoming vehicles, (2) the vehicles overtaking the test car, and (3) the vehicles passed by the test car.

No special instructions were given the driver other than to observe traffic rules and regulations. At the end of the designated road section the observer ceases to count and records the totals on the data sheet as illustrated in Figure 4.

To avoid loss in vehicles counted, the counting was done from the center of the intersecting streets at each end of the section.

One of the sections, No. 4, contained a railroad crossing at grade. The recorders were instructed to keep the stop watch running while awaiting the crossing of trains and then to count the accumulated vehicles. Failure to keep time running would heavily bias the estimated volume if the accumulated cars were then counted.

During the test period, the mechanical traffic counting machines were maintained to an accuracy $\pm$ 3 percent by regularly scheduled fifteen minute manual counts. For each five hour test period there was a minimum of four such fifteen minute manual checks for each machine.

Each car starting at an opposite end of the test grid traveled through each of the ten sections nine times during each of the five test days. This resulted in 90 vehicle runs per section, or a total of 900 runs for the ten sections. These runs were made between the hours of 10:00 A. M. and 3:00 P. M. This period was selected on the hypothesis that traffic flow on urban streets during these off peak hours is uniform and distributed in time as the Poisson distribution.

The data obtained from the above described technique is sufficient for estimating both traffic volume and speed for the section.

USE OF POISSON DISTRIBUTION IN FUNCTIONAL TRAFFIC RELATIONSHIPS

The five hour period from 10:00 A. M to 3:00 P. M. was chosen for this study, as previously stated, because the traffic flow in that period is generally quantitatively uniform. There is a direct relationship between these five hour traffic volumes and the total 24 hour volumes. In the study area these five off peak hour volumes were found to be approximately one fourth of the 24 hour totals. Expansion to 24 hour volumes on the basis of this relationship introduces additional random errors, so that for this study only the five hour estimates were used.

It seemed likely that the flow of traffic in this period was Poisson distributed so that the volume in any given sized time interval would have a mean and variance equal to $n\,t$

where

n = average volume per minute, and
t = minutes of time interval.

This conformity to the Poisson distribution was tested for fifteen minute intervals by the use of Chi square: for each section the five hours were divided into twenty 15 minute periods, with mean equal to $\frac{\text{5 hour volume}}{20}$; for each mean fifteen minute volume a Poisson series was determined; the observed frequencies were then paired with the expected Poisson frequencies and the value of Chi square determined. The results indicated quite conclusively that the hypothesis of Poisson distribution could reasonably be accepted.

It is desired to estimate the five hour volume from a sample of t minutes with n vehicles per minute. Under the Poisson assumption, the mean of the estimate will be $\frac{300}{t}(n\,t)$

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[2] Two recorders were used in preliminary tests. One was found sufficient for the particular details desired.

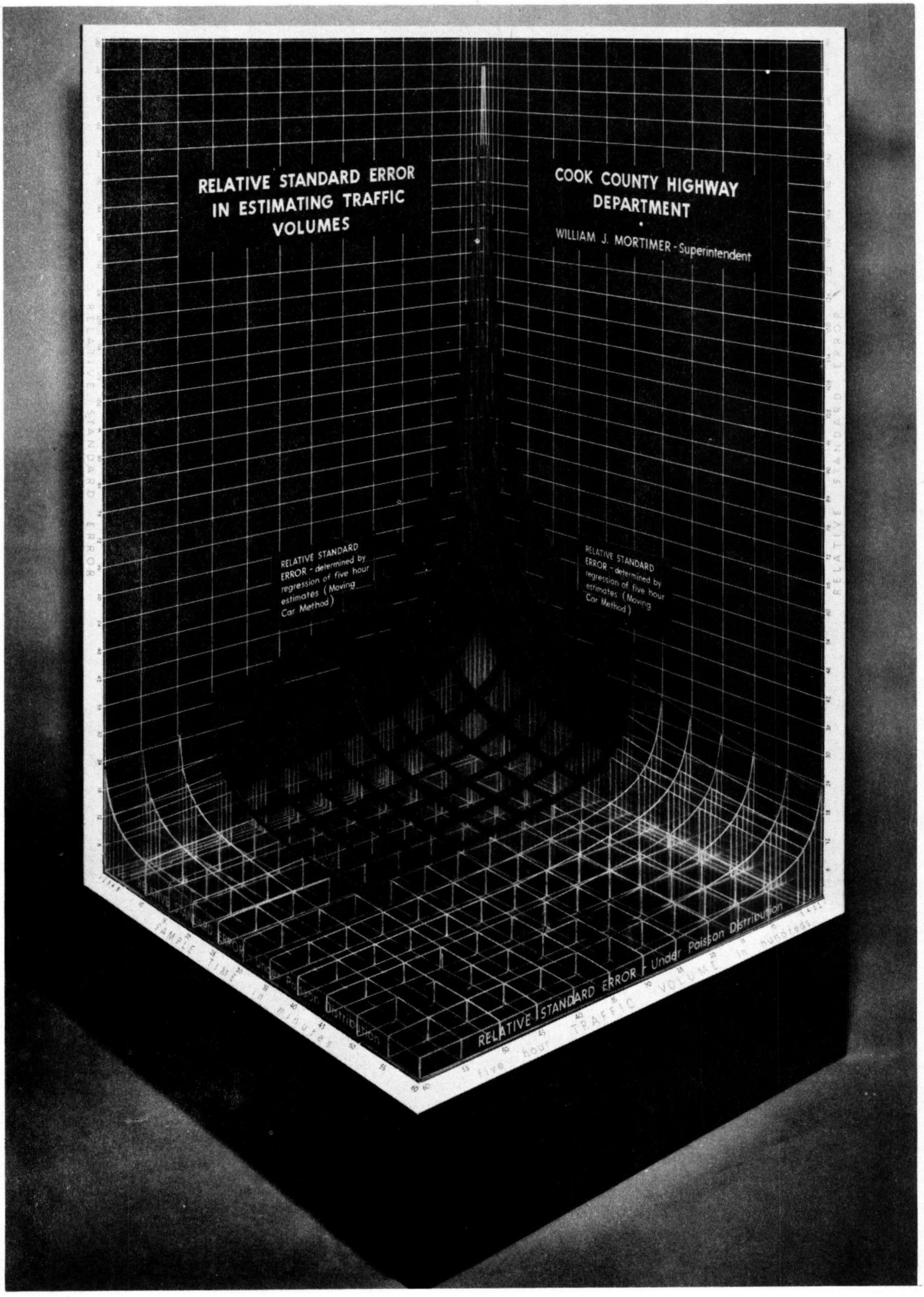
RELATIVE STANDARD ERROR IN ESTIMATING TRAFFIC VOLUMES
COOK COUNTY HIGHWAY DEPARTMENT
WILLIAM J. MORTIMER - Superintendent
RELATIVE STANDARD ERROR - determined by regression of five hour estimates (Moving Car Method)
RELATIVE STANDARD ERROR - determined by regression of five hour estimates (Moving Car Method)
RELATIVE STANDARD ERROR
RELATIVE STANDARD ERROR
SAMPLE TIME in minutes
RELATIVE STANDARD ERROR - Under Poisson Distribution
five hour TRAFFIC VOLUME in hundreds

Figure 4.

and the variance $\frac{300^2}{t^2}$ (n t) or the standard error equal to $\frac{300}{t}\sqrt{n\,t}$, which reduces to $300\sqrt{\frac{n}{t}}$. If it is necessary to study the ratio of the standard error to the 5 hour volume the standard error is divided by 300 n and the result is:

$$k = \frac{1}{\sqrt{n\,t}}$$

$$\text{where } k = \frac{\text{standard error of the 5 hour estimate}}{\text{5 hour actual volume}}$$

This k will be referred to as the relative standard error.

Since it is so often desirable to refer to the relative error, the above formula has been transposed in several ways so as to study:

1. Relative standard error as a function of volume and sample time, $k = \frac{1}{\sqrt{n\,t}}$
2. Volume necessary to achieve a given relative standard error in a given time, $n = \frac{1}{k^2 t}$ and,
3. Time required to achieve a relative standard error with a given volume, $t = \frac{1}{k^2 n}$.

Numerical Examples

1) If n = 50 or 300 n = 15,000

and t = 2

then $k = \frac{1}{\sqrt{50 \times 2}} = \frac{1}{10} = 10$

2) If k = 05

and t = 10

then $n = \frac{1}{0025\ (10)} = \frac{1}{025} = 40$

or 300 n = 12,000

3) If k = 075

and n = 15 or 300 n = 4,500

then $t = \frac{1}{(005625)(15)} = \frac{1}{084375} = 11\ 85$ minutes

The family of curves titled "Poisson relationship of traffic volume and relative standard error to required sample time in estimating 5 hour volume" can be used to find the theoretical sampling time required when the 5 hour volume and relative standard error are specified.

These curves were used in the study of the moving car method and comparisons are made with this family of curves and those curves actually found in the study. These comparisons are discussed in the following section on analysis of field data.

It should be pointed out that these Poisson curves are not limited to use with the moving car method, but can be used with any sampling technique for this five hour period, or can easily be adjusted for use within any time period where traffic flow conforms to the Poisson distribution.

ANALYSIS AND INTERPRETATION OF FIELD DATA

Volumes

The field data were gathered over a five day period between the hours of 10:00 A.M. and 3:00 P.M. for each of 10 road sections. This gave a total of 18 runs per day for each of the ten sections, nine for each day for each direction. The estimates of five

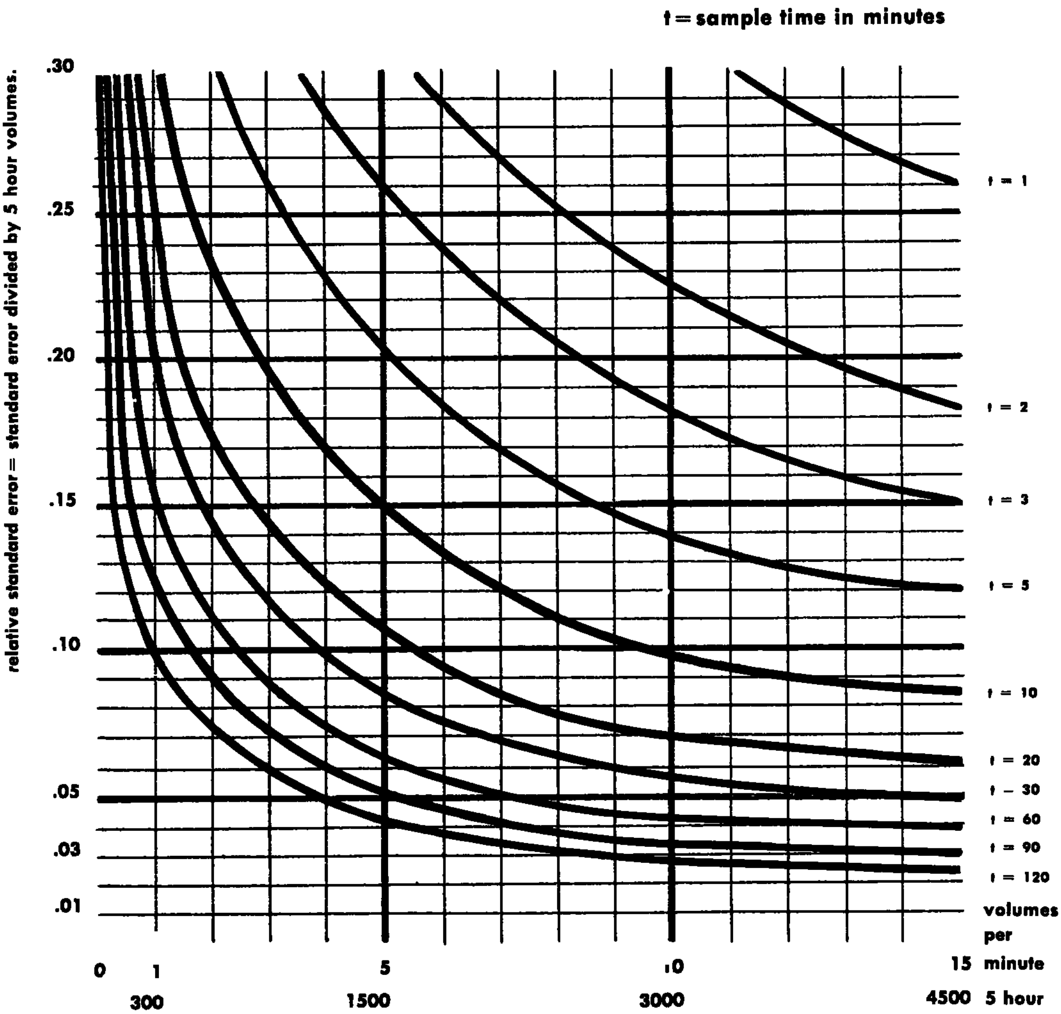

Figure 5. Poisson relationship of traffic volume and relative standard error to required sample time in estimating 5 hour volumes. (Sampling is done between 10.00 A.M. and 3·00 P.M.)

hour two directional volumes were obtained from the formula

$$V = 300\frac{M + (O-P)}{t}$$

Where V = 5 hour estimated volume
M = vehicles met from opposite direction
O = vehicles overtaking the test car
P = vehicles passed by the test car
t = time of the run

If the directional flows for any given section are equal, then as little as one run in either direction can be used for estimating the desired volume. In the ten sections under study for the five off peak hours, the directional flows were found not to be significantly different. Application of the above formula to the data from one run in either direction was found to give an unbiased estimate of the five hour two directional volume. This obviously would not be true when the directional flows differed and if total two way volume were desired in such a case an equal number of runs would have to be made in each direction and the estimate made from the combined total One directional flow can

DATA SHEET

RECORDER Charles Klopp

DAY AND DATE Monday 6/6/55

SECTION Crawford Ave., Touhy Ave. to Howard St.

LENGTH .50

DIRECTION North

Time of Day	Time (Minutes & Seconds)	Vehicles Met from Opposite Direction	Vehicles Overtaking Test Car	Vehicles Passed by Test Car
10:21	0'59"	17	0	2
10:49	0'53"	12	0	0
11:18	0'58"	18	0	1
11:40	1'09"	10	0	0
12:45	0'57"	11	0	1
1:20	1'14"	10	1	1
1:47	1'00"	12	0	1
2:18	0'57"	10	0	0
2:42	0'57"	22	0	1

Figure 6. Three dimensional model portraying the functional relationship between relative standard error, sampling time, and five hour traffic volume.

also be studied, but this involves a slightly different formula (1).

Since it was found possible to obtain unbiased estimates from all volume classes under study, the bulk of the analysis centered around a study of the efficiency of the method under varying volumes and sample times. For each of the ten sections, random combinations were made of the eighteen daily observations, and for each such combination the five hour estimate was computed.

For each day's data the following combinations were used: (1) 18—1 run observations, (2) 9—2 run observations, (3) 6—3 run observations, (4) 3—6 run observations, (5) 2—9 run observations, and (6) 1—18 run observation.

For all such groupings, the means and standard errors were computed. From these, a study was made of the functional relationship between volume, sample time, and standard error. In no section were the means found to differ significantly between groupings.

The following set of graphs illustrates for each of the six time groups the limits of two standard errors around the line "estimated volume equals actual volume." The points plotted around the line show the relation of estimated volume to actual volume. Under an assumption of normality, the indicated limits can be taken as those between which about 95 percent of all estimates will fall.

This assumption is not strictly fulfilled when the number of samples is small, but the two indicated limits give the reader a rough idea of the range of the estimates under varying sample times.

The inner limits are the two standard error limits of the Poisson estimates and the outer limits (indicated by the shaded band) are the two standard error limits of the actual estimates. The discrepancies between the two sets of limits can most likely be explained in terms of random sampling errors.

These limits can be seen to decrease sharply as sample time is increased from 1.3 minutes in the first graph to 23.9 minutes in the sixth graph. For time equal 1.3 minutes the low volume sections (about 300 vehicles per 5 hour period) show standard errors upward of 100 percent while the larger volume sections (3,000 to 5,000 vehicles per 5 hour period) show standard errors of 50 to 60 percent. For time equal 23.9 minutes the low volume sections still show standard errors of 35 to 55 percent while the higher volume sections show standard errors of only 10 to 20 percent.

For the ten combined sections with a total volume of about 22,000 vehicles, the following table indicates for each of the given number of runs per section, the standard error of the sum of the estimated volumes and the proportion of the standard error to the actual total volume. This estimate of total volume would be of use mainly in determining total vehicle miles traveled.

Number of runs (R) per section and average total time (t) in minutes.

Total volume equals 22,000 vehicles.

R	1	2	3	6	9	18
t	13 4	26 4	39 7	79 8	119 4	239 1
Standard error of the sum of estimates	2813	1994	1661	1025	987	871
Relative standard error	128	091	075	047	045	040

It can be seen from studying this table that as the number of runs is increased from 6 to 18, the relative standard error diminishes very slowly. There is clearly some point beyond which the further reduction in error is not worth the added cost and time spent. This point would have to be determined in each case and would depend primarily upon the use to be made of the data.

Another set of graphs follows which shows relative standard error as a function of volume. The Poisson determined curve is also plotted so as to provide a direct comparison of actual relative standard error to expected Poisson relative standard error. The bounds of the Poisson determined expectancies are indicated by the single black line curve, and the bounds of the observations are shown by the extent of the shaded section.

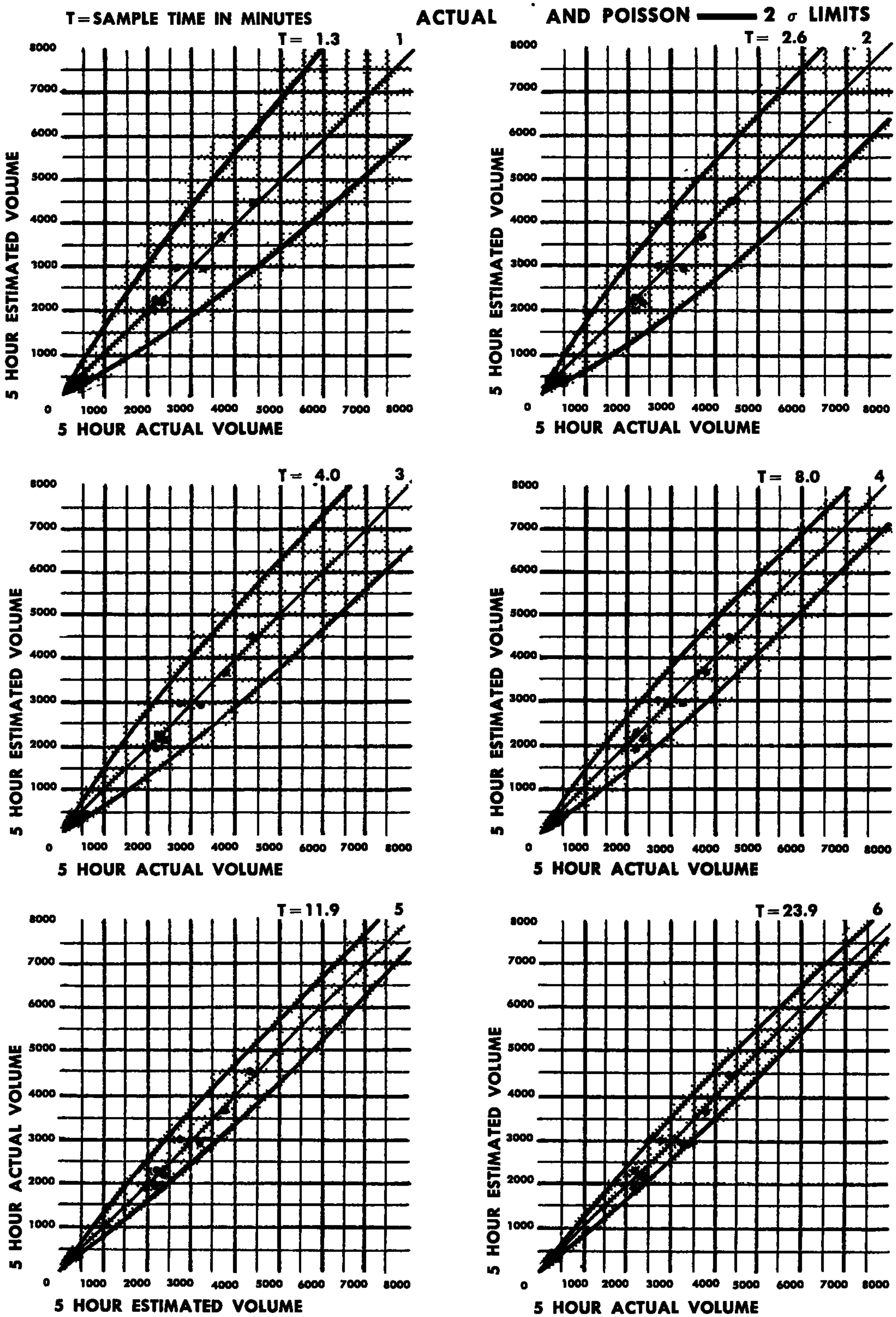
T=SAMPLE TIME IN MINUTES
ACTUAL AND POISSON 2 σ LIMITS
T= 1.3
1
T= 2.6
2
T= 4.0
3
T= 8.0
4
T=11.9
5
T=23.9
6
5 HOUR ESTIMATED VOLUME
5 HOUR ACTUAL VOLUME
5 HOUR ACTUAL VOLUME
5 HOUR ESTIMATED VOLUME
0
1000
2000
3000
4000
5000
6000
7000
8000

Figure 7.

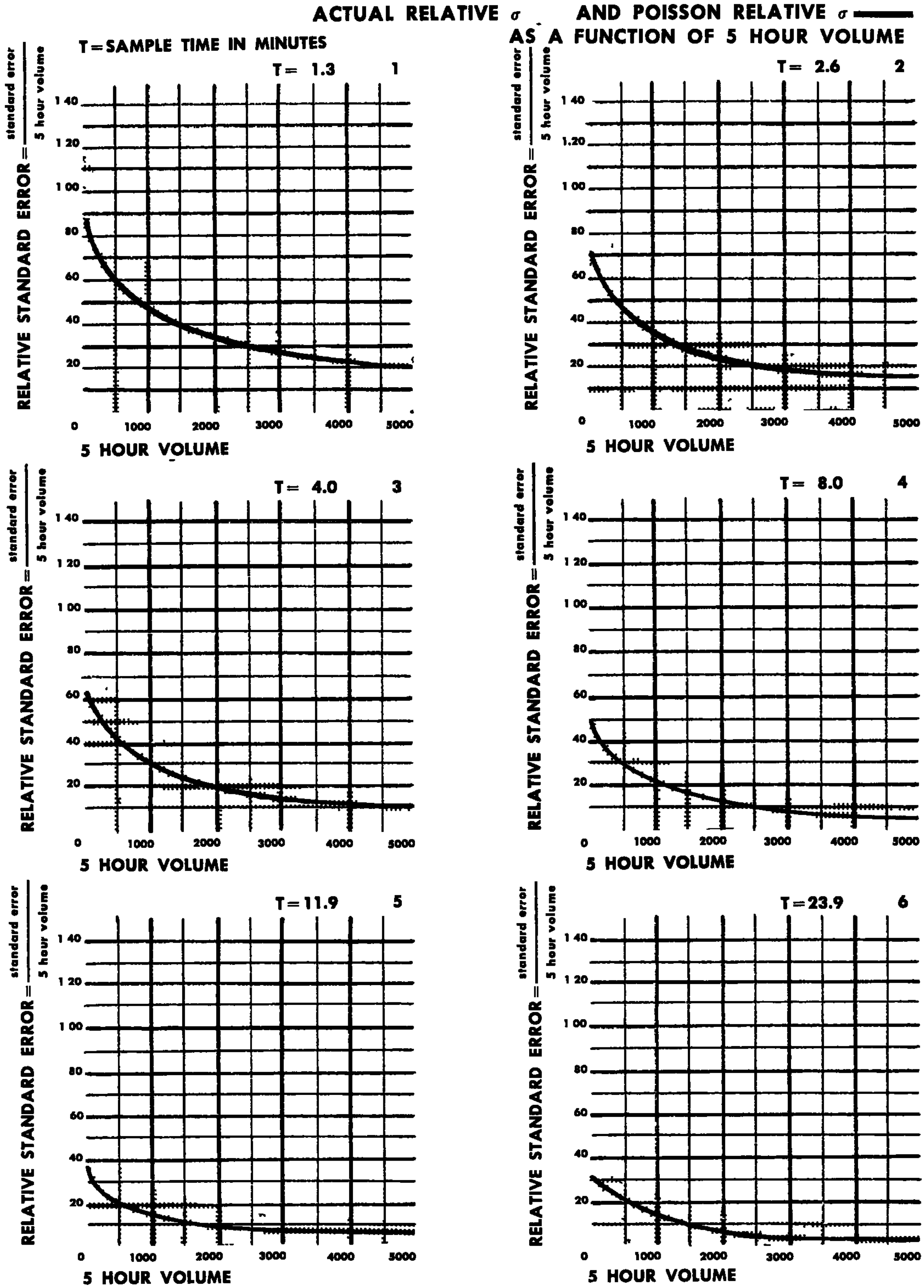
ACTUAL RELATIVE σ AND POISSON RELATIVE σ
AS A FUNCTION OF 5 HOUR VOLUME
T=SAMPLE TIME IN MINUTES
T= 1.3 1
T= 2.6 2
T= 4.0 3
T= 8.0 4
T=11.9 5
T=23.9 6
RELATIVE STANDARD ERROR = standard error / 5 hour volume
1 40
1 20
1 00
80
60
40
20
0
1000
2000
3000
4000
5000
5 HOUR VOLUME

Figure 8.

A multiple regression study was done to predict standard error as a function of volume and sample time. The resulting formula is:

$$Y = 297.4 - 19.3\,X_1 + 143\,X_2$$

where Y = estimated standard error
X_1 = sample time in minutes
X_2 = 5 hour volume of section

The regression itself has a standard error of 186.2. The value of R^2 is 0.661 indicating that the regression accounts for about 66 percent of the total variation in standard error. Both regression coefficients were highly significant. Within a limited range this regression is a fair predictor.

A second regression study was done to predict standard error as a function of the Poisson determined standard error, $300\sqrt{\frac{n}{t}}$.

The resulting equation was:

$$Y = 1.245\,X - 4$$

where Y = estimated standard error
X = Poisson determined standard error, $300\sqrt{\frac{n}{t}}$.

R^2 was found to be 0.912 indicating that about 91 percent of the variation in standard error can be accounted for by the regression. The standard error of estimate for the regression was 94.7 a significant reduction of the value found in the preceding regression.

The regression coefficient was found to be highly significant, but the constant, −4, was found not to differ significantly from zero. The regression is a highly efficient predictor of standard error, which further substantiates the assumption of Poisson distribution.

Speeds

Suppose it is required to estimate the average speed of traffic for both directions on a given section of road. The average time required to drive through the section in each direction must first be computed. This is found to be:

$$t_r = t_1 + t_2 - \frac{(O_1 + O_2 - P_1 - P_2)}{V}$$

where t_r = driving time for a round trip
t_1 = driving time for one direction
t_2 = driving time for other direction
O_1 & O_2 = vehicles overtaking test car while traveling in directions 1 and 2 respectively
P_1 & P_2 = vehicles passed by test car while traveling in directions 1 and 2 respectively
V = two directional estimate of traffic flow per minute

It is a simple matter to convert the driving time to speed. One directional speed can also be studied by use of this method (1), but for this study the uni-directional speeds were assumed equal. This assumption was tested over the ten sections under study and found acceptable.

The average speed of traffic for use as control was found by two methods: (1) the radar tested speed across a given point, and (2) the time required for a vehicle to travel the entire section as measured by standing observers at each end of the section, using synchronized stop watches. A 20 percent sample was taken and vehicle identification was accomplished by the license plate method.

The radar tested speed, as might be suspected, tended to be higher than the speed computed by the other method. Since the travel time for the section included stopping at the end of the section, the second method was used as the control.

The average actual speed for the ten sections was 27.4 mph and the average estimated speed 24.5 mph. The average error of estimate was −2.9 mph with standard deviation equal to 1.8 mph. On the basis of these figures alone, the hypothesis of zero average error could not reasonably be rejected. However, in all ten sections, the estimated speed was found to be an underestimate of the control speed. A sign test would be highly significant and lead to the rejection of the hypothesis that the estimate was as likely to be above as below the control speed. For the ten sections under study, the latter test seems more indicative of the technique.

Referring to the formula for average time required to drive a round trip on the section,

$$t_r = t_1 + t_2 - \frac{(O_1 + O_2 - P_1 - P_2)}{V}$$

it is seen that if the test car drives the run at the average speed of all cars driving the run, then the only factor influencing the estimate of speed is the number of overtaking and passed vehicles. These are assumed to balance in the long run. However, in this study, there was a marked tendency for the number of vehicles passed by the test car to be greater than the number overtaking it. The explanation for this seems to lie in the nature of the road sections studied. In a residential, suburban, or business area, there is a tendency for vehicles to slow down to turn, park, etc. This tendency would increase the probability of the test car passing a vehicle and hence upset the balance assumed to exist between vehicles overtaking and vehicles passed by the test car. Where the number of passed vehicles is small relative to the estimated flow the effect of this imbalance may be negligible, but where it is large (especially noticeable on low volume sections) the effect is significant, and will produce an underestimate of speed as measured by the standing observers at each end of the section. It must be pointed out that only the through traffic passes both observers within a useful comparative time period so that the observer method almost certainly produces an overestimate of the true average speed of all traffic on the section. In any event, on high volume sections or on sections where turning and stopping are minimized, the moving car technique should give an unbiased estimate of speed.

APPLICATION

Volume counts on a street system are now secured by machine or manual counts. These existing methods require machines and manpower in various proportions. Any extensive counting program might require the use of a substantial number of men and machines not readily available.

The techniques presented in this paper will provide a method of volume counting which will require a bare minimum of manpower and equipment. It offers a means of securing economically and quickly a blanket volume count of all streets in a given area.

Such information as vehicle miles of travel on a road network, volumes over this road network, vehicle classifications and vehicular speeds may be realized from this technique.

Comparative operating time and cost of this method over current methods will vary with specific problems, but appears to be substantially lower in many cases.

For example, a one hundred mile network of roads could be covered once by this method in less than five hours with one car and two men.

For varying total volumes of a given network, the following table indicates the standard error expected in estimating the sum of the volumes of the individual sections. This is on the basis of one covering of the network:

Sum of the volumes of the individual ½ mile sections	Expected Standard error	Relative Standard error
50,000	4,157	0.083
100,000	5,896	0.059
200,000	8,327	0.042
300,000	10,203	0.034
500,000	13,170	0.026
1,000,000	18,630	0.019

This table emphasizes the potential of the moving car method for blanketing road systems quickly, economically and accurately.

Three methods for obtaining total vehicle miles traveled were suggested in a previous paper (3). Each method is listed below along with the time required to obtain volume estimates for computing total vehicle miles traveled on a 100 mile network of roads (2 miles square with 25 x 25 grid of streets).

1. A six minute manual traffic count eight times a day in each block. Totaling 1,650 man hours.

2. A one hour manual count at every other intersection. Travel time plus 312 man hours.

3. Mechanical non-recording counts at approximately every five blocks. One hundred man hours plus 6,000 machine hours.

Assume that the individual sections have 5 hour volumes of 250 vehicles or a combined total of 50,000 vehicles for 200 one-half mile sections. Then the moving car method would require 11 runs or about 96 man hours to insure against errors exceeding ± 5 percent, but for errors ± 10 percent only three runs would be necessary, or a total of 26 man hours.

If the individual sections have as much as 2,500 vehicles per five hour interval, then one run or less than 9 man hours would insure against errors exceeding 5.2 percent.

SUMMARY

For the five off peak hours the hypothesis of Poisson distribution of traffic flow was found acceptable.

The moving car method was found to produce an unbiased estimate of the five hour bi-directional traffic volumes.

By regression analysis it was found that the standard error of the five hour estimated volume could be reasonably determined by the relationship

$$\text{S.E.} = 1.245 \text{ Poisson's S.E.} - 4,$$

$$\text{where Poisson S.E.} = 300 \sqrt{\frac{n}{t}}$$

The standard error in estimating the five hour volume is sufficiently small in certain applications to consider the use of this method in preference to other existing methods.

Although it appears that an unbiased estimate of speed can be obtained from this method, the fact that the control speed tended to overestimate true speed points to the need for further study.

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Speed and Travel Time Measurement in Urban Areas

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The Committee on Operating Speeds in Urban Areas was organized for the purpose of developing a technique for measuring the speed of traffic on urban facilities on an annual average basis. Travel time data are useful in making economic appraisals of road-user costs and benefits, in predicting the diversion of traffic from old to new or improved facilities, and in other related analyses. Various methods for sampling speed or travel time have either been investigated by members of the committee or the results of other investigations examined. The merits as to accuracy, economy, and practicability of several methods for determining travel time are compared. These include: (1) license matching method; (2) floating car methods (of which there are several variations); (3) spot speed method; (4) arrival-output volume rate method; (5) interview method; (6) photographic method. Variable conditions that affect the speed of traffic are discussed and coverage is given to the guiding principles for scheduling speed studies throughout the year so that the annual average speed on a facility may be determined.

●TRAVEL time data are used for several purposes by traffic and highway engineers. Some of these uses are: (1) the identification of locations and causes of delays on urban streets, (2) predicting the diversion of traffic from old to new or improved facilities, and (3) analyzing road-user benefits. In an economic appraisal of road-user benefits, one of the factors that must be weighed is the element of time spent by drivers in traversing a particular section or sections of highway. Travel time is a function of speed and distance. Thus it is of some importance that there be a reliable means of ascertaining the speed of traffic over the particular section of highway under investigation. Since this speed will vary between various hours of the day, days of the week, and seasons of the year, it is not sufficient that the speed be known for a short period of time. It is customary for the highway economist to compute user benefits on an annual basis.

Of the various techniques that have been employed for measuring speeds, or travel times, none has had the complete confidence of the highway engineer. This is true of the determination of average speed during the short period of time for which the technique was actually applied. Considerable doubt may also be attached to the results obtained by expanding a short-period observation into an annual average figure.

The Committee on Operating Speeds in Urban Areas was organized for the purpose of developing a technique whereby the speed of traffic on urban facilities might be measured with a reasonable degree of accuracy on an annual average basis. Desirable features, other than accuracy, would be simplicity and economy of operation. This is a report of accomplishment of the committee.

PROGRAM

The program as adopted called for testing the accuracy of various methods for determining over-all travel speeds on a short-time basis. Such tests were to be made under fixed conditions. Any method or methods that met the test of accuracy, simplicity, and economy would then be utilized in developing a technique for sampling over-all travel speeds for all conditions that could be applied in determining the average over-all speed and travel time on an annual basis.

STUDY METHODS TESTED

Several methods of studying travel times were suggested, and most of these have been tested in some degree. Methods suggested were:

License Matching Method. By this method the license numbers of all vehicles, together with the time of day that they pass two selected points (the terminal points of the test course) are observed and recorded. The numbers are later matched, the travel time of each vehicle is determined, and an average speed value obtained.

Floating Car Method. In this method a test vehicle is driven over the test course at a speed approximating the average speed of traffic.

Spot Speeds of All Traffic at a Selected Point as Related to Over-All Speeds. A speed-measuring device is used to determine the speeds of all vehicles as they pass a selected point on the test course, and the average spot speed is then related to the over-all speed over the entire course.

Arrival-Output Volume Rate Method. This method is adaptable to the controlled-access type of facility only, where there is reasonable certainty that the components of traffic passing one terminus of the test section will also pass the other terminus. Briefly, the method consists of isolating a segment of the traffic stream (all traffic within a given period of time) and determining the average time at which all increments of the segment of traffic pass each of the two termini of the test section.

Interview of Drivers. A large number of private drivers are questioned, by personal interview or through correspondence, as to their routes of travel, time of day trips were made, the travel times involved, locations and causes of excessive delays, etc. Data are classified and summarized according to route of travel and time of day.

Ground or Air Photographs. Photographs of the traffic stream are taken at fixed time intervals with a specially designed motion picture camera. Spot speeds can be determined by measuring on the photographs the distance each vehicle moves during the fixed interval of time between two successive photos. Travel time for relatively short sections of road (such as 300 to 1,500 ft at the approach to an intersection) may also be determined by taking a series of photos at a uniform time spacing and counting the number of pictures or "frames" which are required for each vehicle to move from one end of the section of road to the other.

Results of Investigations

Results of investigations of some of the above-named methods of study have been reported. In 1949 Berry and Green compared various driving techniques for the floating car method and the license check method on two urban streets in California (2). In 1951 Roy B. Sawhill investigated various travel time techniques on a rural two-lane highway (3). Also in 1951 Berry enlarged upon his earlier investigations and reported his findings in a paper entitled, "Evaluation of Techniques for Determining Over-All Travel Time" (4). Meanwhile the Bureau of Public Roads cooperated with other agencies in investigations involving travel time techniques. This report will draw upon all of the aforementioned material but will not repeat in full that which has already been published. The various techniques for short period study will be discussed separately, followed by a discussion of expansion methods for determining annual travel time.

License Matching Method

The license matching method has been accepted by the committee as being a reliable standard upon which to base the accuracy of other methods. Where all license numbers are recorded and the exact time of passage of each vehicle is observed, little question can be raised as to the accuracy of results insofar as travel times for vehicles which traverse the entire test section are concerned. Such a process is neither simple nor economical, however. Observers find difficulty in reading all numbers, particularly so where traffic volumes are high. The matching of numbers and subtracting the time of passage is also time-consuming. Sawhill determined that 9 man-hours were required (field and office combined) for each hour of field observation on a heavily traveled two-lane road. This includes 2 man-hours for field observers using voice-recording instruments, 4 man-hours for office transcriptions, and 3 man-hours for matching numbers. The latter item would vary with the volume of traffic, and the total time would vary somewhat with the field procedure employed.

Voice-recording instruments afford considerable saving in manpower in the field, but a part of this saving in man-hours is offset by the time consumed in transcribing the field records. Some saving in time can be effected by sampling the traffic during the period of field study. Both Sawhill and Berry have concluded that sampling is practicable and have conducted research toward a determination of the size of sample needed. Table 1 shows the needed sample sizes for results that are within 5 percent of the true average speed in 95 cases out of 100.

To be truly representative, the sample should be distributed systematically throughout a period or periods of observation during which traffic volumes change but little, if any. One means of assuring a systematic distribution would be to select licenses ending in certain digits, such as 0 and 5. The number of different digits to be employed would be dependent upon the volume of traffic and the percent of through traffic. These items can be determined by preliminary study.

TABLE 1

NUMBER OF LICENSE-NUMBER MATCHINGS NEEDED FOR DETERMINING MEAN OVER-ALL SPEEDS ON VARIOUS TYPES OF FACILITIES WITH AN ERROR NOT TO EXCEED 5 PERCENT WITH A 95-PERCENT DEGREE OF CONFIDENCE (4)

Type of facility	Number of license matchings
Signalized urban streets	
Two-lane, uncongested	32
Two-lane, congested	36
Multilane, uncongested	80
Multilane, congested	102
Rural highways	
Two-lane, 1,130 v p h	25
Two-lane, 1,440 v p h	41
Four-lane, uncongested	30

The saving in man-hours through use of a sampling procedure is very much worthwhile. On many streets, one person at each end of the test section would be able to observe and manually record times of passage and license numbers for a sample of one or two license number endings for one direction of traffic. Transcription time would thus be eliminated, and the total man-hours per hour of field observation would, according to Sawhill's estimate, be reduced to three. With only a slight sacrifice in accuracy, a saving of up to two-thirds in man-hours may be realized through use of the sampling technique.

When manually recording or transcribing license numbers, the matching process is facilitated if all numbers with the same license number ending are recorded in the same column. (See sample field sheet, Fig. 112, p. 125 of reference 7.)

The percent of through traffic (vehicles which pass both ends of a section of street) may be relatively low on some sections of urban street, because of the high number of vehicles entering or leaving the street at intersections between the ends of the section. In such cases the length of test section must be shortened. A preponderence of traffic should be through vehicles that pass both termini. This will generally be the case on arterial-type streets, but on other parts of the urban street system it may be necessary to divide the study section into undesirably short segments.

The committee accepts the license matching method of study as being the most accurate of all methods when a 100 percent sample is used. The committee also recognizes it as being among the most economical and practical of methods if a sample is so selected as to produce results comparable in accuracy with those attainable by the other methods tested. If, however, an investigation of speeds should have for its purpose the identification of locations and causes of delays, the license matching method is not as well suited as others of the methods tested.

Test-Car Technique

The floating-car technique, of which there are several variations, has been in rather common use for many years. For this reason the committee felt that early attention should be given to testing the validity or accuracy of this method. It is a general practice, in using the floating-car technique, for the driver to pass as many vehicles as the number passing him. It has been assumed that by so doing the speed of the floating car or test car would approximate the average speed of all traffic. For this assumption to be valid, the test vehicle must remain in the traffic stream for a sufficient period of time to be exposed to a representative sample of traffic.

Where traffic is heavy and there are frequent signalized intersections it might be supposed that the travel time of all vehicles would be very nearly the same and that an individual driver would have little choice in selecting his speed. To determine whether or not this is in fact the case, tests were made by Berry and Green (2), using three driver techniques. These were:

1. Driver to travel at a speed which, in his opinion, is representative of the speed of all traffic at the time. (Designated as an "average test run;" somewhat different from standard "floating car" technique.)

2. Driver to maintain a maximum speed consistent with safety and existing traffic regulations. ("Faster" test run.)

3. Driver to maintain a place in the traffic stream but to gage his speed by the slower vehicles. ("Slower" test run.)

Tests were made on three streets, and the effect of traffic volume was also investigated. Results were checked by the license matching method. The tests showed that there may be a wide variation in the speeds of test vehicles, depending upon which of the three driver techniques is employed. The more important conclusions as reported for this investigation may be summarized as follows:

1. Test cars driven at maximum speeds consistent with safety, or at speeds approximating those of the slower vehicles on the street, usually do not yield travel times which are an accurate measure of the average travel time of vehicles in the traffic stream. The range in travel time for these extremes in test car techniques, however, is small for streets with closely spaced traffic signals.

2. Test cars driven at speeds which in the opinion of the drivers are representative of the average speed of traffic can provide an accurate means of measuring the mean and median travel times of vehicles in the traffic stream of heavily traveled signalized streets.

3. Travel times vary greatly when the traffic volume on signalized streets reaches and exceeds the capacity of the intersections of a test section. Travel-time variation is much smaller for volumes below the capacity of the intersections.

The study by Berry and Green referred to above was later extended to include additional streets and, more particularly, to compare the "average driver" technique with the conventional floating-car technique. It was found that both "floating" and "average" test runs made in adequate number yielded results, on most of the urban street sections tested, within 7 percent of the mean travel time obtained by the license matching method. While it was concluded that either of these test-vehicle methods would produce satisfactory results if sufficient runs are made, more test-car runs are needed for the "floating-car" method than for the "average-car" method, for specified limits of error. The following table from Berry's report shows the approximate numbers of "average" test-car runs needed to produce mean over-all speeds within certain limits of accuracy. It should be apparent that in order to obtain results with an error no greater than 10 percent, several test cars would be needed in most cases, or tests would be required by one or more cars on several different days during periods when all conditions as to traffic, weather, etc., were similar.

The number of test runs needed to determine travel time for a given set of conditions should be made during periods when those conditions apply. Then the results for these runs will be representative of the average over-all travel speed of all traffic for that particular set of conditions. The relatively large number of test car runs indicated for an accuracy of 5 percent suggests that this method is impractical where a close approximation of travel time is desired.

TABLE 2

NUMBER OF "AVERAGE" TEST CAR RUNS NEEDED FOR DETERMINING MEAN OVER-ALL SPEEDS ON VARIOUS TYPES OF FACILITIES WITHIN DIFFERENT LIMITS OF ACCURACY FOR 95-PERCENT DEGREE OF CONFIDENCE (4)

Type of facility	Number of test car runs needed to produce results with a maximum error of	
	5 percent	10 percent
Signalized urban streets		
Two-lane, uncongested	30	8
Two-lane, congested	40	10
Multilane, uncongested	18	5
Multilane, congested	50	13
Rural highways		
Two-lane, 1,130 v.p h	25	6
Two-lane, 1,440 v p h	42	11

Summary of Test-Car Methods

The investigations covering the various test-car techniques for making over-all travel-time studies are sufficiently extensive to permit the following conclusions:

1. "Average" test cars, driven at speeds which, in the opinion of the drivers, are representative of the average speed of all traffic can provide a practical measure of the mean travel time and the mean over-all travel speed of vehicles in the traffic stream of heavily traveled signalized urban streets and rural highways.

2. Floating test cars, in which the driver is instructed to pass as many vehicles as pass his vehicle, may also provide a practical measure of mean travel time of vehicles in a traffic stream on heavily traveled signalized streets. On multilaned streets, floating test cars produce results which are less reliable than the results obtained with the same number of runs of "average" test cars.

3. The preferred instruction for test car drivers is to specify that each driver should maintain a speed which, in his opinion, is representative of the average speed of all traffic in the stream.

4. The test-car methods may be unreliable during periods when traffic volumes are low.

5. Where locations and causes of delays are to be identified, the test-car method has an advantage over the other methods investigated.

Spot Speeds

For a number of years it has been a practice in many states to make periodic studies of the speeds of all vehicles, or a selected sample of vehicles, as they pass a predetermined point along the highway during a period of observation. Such studies, where instantaneous speeds of vehicles are determined, are commonly called "spot-speed" studies. Procedures for obtaining spot speeds have been simplified during recent years by the development and improvement of speed measuring devices, and the conduct of such studies is now a relatively simple operation on rural highways, particularly those carrying low traffic volumes.

If a relationship exists between average spot speeds and average over-all speeds, and if such relationship can be established, then the spot speed technique might be a useful and economical device for obtaining average over-all speeds. It is readily apparent, however, that the relationship between spot speed and over-all speed, if such actually exists, would vary between different sections of highway depending upon their length, profile, traffic volume, frequency of intersection control devices, and numerous other variables. Thus, the over-all speed for a section of highway must first be known before the relationship can be established. It is extremely doubtful that a true relationship between the two can be established on urban surface streets where traffic flow is interrupted by signals or other controls. For this reason the committee has not investigated the usage of the spot speed method on streets of the type described. Spot speed observations are useful for enforcement purposes, for establishing speed zones, and for developing speed trends, but they are of limited use in determining speeds where travel time is the ultimate objective.

The committee believes that the usefulness of spot speed studies, insofar as determining over-all speeds is concerned, is confined to rural highways and free-flowing urban facilities, such as freeways and arterial streets protected by stop signs and with little traffic entering or leaving. Even on free-flowing facilities the principal application would be in making either repeat studies or studies for an extended period of time. As has already been mentioned, the mean over-all speed during a limited period of study will have to be determined by some reliable means while the spot speed study is in operation. This operation will be necessary for every section of highway studied.

Such tests as have been made of spot speeds on rural highways cast some doubt upon the reliability of the method. Sawhill (3) found that the mean travel time as converted from spot speeds on a heavily traveled two-lane rural road showed erratic results. The mean, as compared with a license check, was, on the average, 6 percent too high when traffic was moderately heavy and 6 percent too low when traffic was heavy. He suggests the possibility that taking spot speeds at two or more locations might give more stable results.

In another test, on US 1 in Maine, spot speeds were observed on each of six sections of highway for which mean over-all speeds were obtained by the license matching method.

On the six sections the average spot speed exceeded the average over-all speed by an amount varying from 15 to 25 percent, with the greater disparities occurring on the shorter sections. On any one section the ratio of spot speed to over-all speed remained fairly constant from hour to hour throughout a single day. However, on successive days, Saturday and Sunday, the ratio changed markedly. The traffic volume was not greatly different on the two days, being below the practical capacity of the facility in both cases, and the variation in the ratio was very probably caused by the character of traffic and differences in trip purpose.

The committee does not recommend the spot speed method as a measure of mean over-all speeds unless the relation to over-all speed is carefully investigated for the particular section of highway being studied and is found to be reliable.

Arrival-Output Method

This method is applicable to sections of highway where there is no access or egress between the termini of the section. The theory of the method is somewhat similar to that of the license matching method in that the object is to obtain the average time of

TABLE 3

DETERMINATION OF AVERAGE TRAVEL TIME BY LICENSE MATCHING METHOD

Example

License number	Time of passage		Travel time
	Station 1	Station 2	minutes and seconds
(1)	(2)	(3)	(4)
9,335	8·00:12	8:04:05	3:53
42,143	:58	05:29	4:31
7,963	01:21	:19	3:58
15,142	:44	:49	4:05
4,872	:59	—	Not matched
7,615	02:19	:39	3:20
25,166	·35	06:11	3:36
8,327	:41	—	Not matched
1,144	:52	07·12	4:20
31,579	03:09	:28	4:19
67,156	:36	:07	3.31
3,218	:55	:39	3:44
7,244	04:47	08:56	4:09
16,288	05:07	09·25	4:18
Average	8:02:43	8:06:41 -8:02:43	3:58
Difference		3·58	

passage of all vehicles that pass the two terminal points of the study section. In the license matching method sufficient information is obtained to permit the travel time of each individual vehicle to be determined. Such detailed information is necessary where a distribution of speeds or travel time is desired. However, if an average travel-time value alone is sought, it is not necessary to determine each individual travel time; such an average value can be obtained more simply be determining the average time of day that all vehicles for which the numbers match passed each of the two points of observation. The difference between these two averages is the average travel time. This may be illustrated by the simple example shown in Table 3.

In this example the computation in the fourth column of the table is not essential to a determination of the average travel time because that value can be obtained more easily from the average values in columns 2 and 3. The license numbers in the first column serve only one purpose: to eliminate those vehicles which did not traverse the entire section, or for which because of some other reason, the time of passage was not recorded at both stations.

Between interchanges on a controlled-access type of facility, all vehicles would traverse the entire section; hence license numbers need be recorded only to assure that neither of the two observers fails to record the time of passage of one or more vehicles during the study period, or, if they should fail, then to permit the elimination of that vehicle from the sample. During the first few minutes of operation and during the final closing minutes of the study, license numbers must be read and matched, but during the intervening or major portion of the study period it should be unnecessary to note license numbers, provided the time of passage of each and every vehicle is recorded. On controlled-access facilities where traffic volumes are comparatively light it is not difficult to observe the time of passage of every vehicle and the procedure just described is very appropriate to that condition

Where the traffic volume is heavy it may be impossible to record the time of passage of every vehicle, but in that case a further simplification of the procedure is possible. Then it is sufficient merely to count the numbers of vehicles passing each station during 60-second intervals because the traffic will be sufficiently well distributed throughout each minute that, on an average, they may all be assumed to have passed at the midpoint of the minute. By making use of a test car to inform the observers when to start and stop their count, the reading of license numbers can be entirely eliminated. At each station the count is started at the instant the test car passes that station. The travel time of the test car must be very carefully measured by someone in the car, and an accurate record must be kept of the number of times that it passed or was passed by other vehicles. The counts are terminated in the same fashion. The procedure will be illustrated by an example.

In this example, the following are assumed:

1. To start the study the test car passed Station 1 at 8:30:00 and Station 2 at 8:30:55. In making the starting run the test car was passed by two vehicles. At each station counts were started at the time the test car passed the station and were continued, for each 60-second interval, for the duration of the study.

2. The count was terminated by a similar test run. The test car passed Station 1 at 8:44:35 and Station 2 at 8:46:26. In making the terminating run, which was the signal for the observers to stop counting, the test car was passed by one vehicle.

In Table 4, the numbers of vehicles as counted at the two stations are shown in the second and fifth columns. Note that the counts for the first and final counting periods have been adjusted to correct for the vehicles that passed the test vehicle. Computations are shown in the third and sixth columns of the table.

It should be apparent that results of the arrival-output method are conditioned upon:

1. Accuracy in counting traffic.
2. Complete absence of any access or egress to or from the highway within the study section.
3. Accurate timepieces.
4. Care in beginning the study period at the instant the test car passes each station on the initial run.
5. Uniform spread of vehicles over each minute.

If these essentials are met, the results are certain to be correct, provided the study is continued for a period of at least several minutes Although its field of application is very limited, it is nevertheless a useful, economical, and accurate device for obtaining average over-all travel time where highway conditions are suitable.

Interview Method

The interview method may be useful where a large amount of material is needed in a minimum of time at little expense for field observations. Collection of the field data is performed by a segment of the motoring public and this activity should be preceded by the issuance of instructions, either oral or written, to those who are to participate in the study. Commercial or business firms provide a convenient medium through which such instructions may be issued and through which field data can be assembled. The cooperation of strategically located firms or establishments should be obtained as a preliminary to such a study.

Forms on which the desired information is to be recorded are issued to motorists who volunteer for the study. On these forms, space is provided for entering informa-

TABLE 4

COMPUTATIONS FOR DETERMINING AVERAGE TRAVEL TIME BY ARRIVAL-OUTPUT METHOD

Example

Station 1			Station 2		
Time: 60-sec. period after 8:30:00	Number of vehicles	Computation	Time: 60-sec. period after 8:30:55	Number of vehicles	Computation
1	26	0.5x26 = 13.0	1	25	0.5x25 = 12.5
2	35	1.5x35 = 52.5	2	30	1.5x30 = 45.0
3	31	2.5x31 = 77.5	3	32	2.5x32 = 80.0
4	39	3.5x39 = 136.5	4	36	3.5x36 = 126.0
5	26	4.5x26 = 117.0	5	40	4.5x40 = 180.0
6	33	5.5x33 = 181.5	6	31	5.5x31 = 170.5
7	29	6.5x29 = 188.5	7	26	6.5x26 = 169.0
8	37	7.5x37 = 277.5	8	24	7.5x24 = 180.0
9	24	8.5x24 = 204.0	9	29	8.5x29 = 246.5
10	28	9.5x28 = 266.0	10	27	9.5x27 = 256.5
11	38	10.5x38 = 399.0	11	33	10.5x33 = 346.5
12	35	11.5x35 = 402.5	12	36	11.5x36 = 414.0
13	30	12.5x30 = 375.0	13	40	12.5x40 = 500.0
14	27	13.5x27 = 364.5	14	28	13.5x28 = 378.0
15 (35 seconds)	19	14.3x19 = 271.7	15 (21 seconds)	20	14.2x20 = 284.0
Total	457	3,327.2		457	3,388.5
Average		3,327.2 ÷ 457 = 0:07:17 + 8:30:00 = 8:37:17			3,388.5 ÷ 457 = 0:07:25 + 8:30:55 = 8:38:20

Average travel time = 8:38:20 minus 8:37:17 = 1 minute, 3 seconds.
Note: Count for first period at Station 1 is reduced by two vehicles because that number passed test vehicle during starter run. Count for 15th period reduced for similar reason.

tion such as: date, time of beginning of trip, weather conditions, termini of trip, and trip data, to include space for entering the locations of key points along the route traveled, together with the time of arrival (hr., min., and sec.) at these key points, odometer readings at key points (miles and tenths), and remarks.

Instructions may be printed on the reverse of the form. Test runs may be performed on one day only or they may be spread over a much longer period of time.

With good cooperation, the results obtained by the interview method may be very satisfactory for the particular set of conditions under which trips were made. Collection of field data is inexpensive and a large area may be covered in a very short period of time. Disadvantages of the method are: (1) observations are limited almost entirely to peak-hour conditions, (2) the results do not lend themselves readily to expansion to average travel times on an annual basis (support for repeat studies at frequent intervals throughout the year would be difficult to obtain), (3) the agency performing the study has little flexibility in specifying routes to be followed or the weather or other conditions under which the observations are to be made, and (4) the sorting and classifying of trips, the computation of travel times, and summarization of data are tedious operations.

Photographic Method

The photographic methods are primarily research tools because the interpretation of the photographs is a tedious task and transcription of the data is time consuming. Photographic methods are most useful in studies of interrelationships of several factors such as speeds, spacings, lane usage, acceleration rates, queue formations, merging and crossing maneuvers, and delays at intersections.

Spaced serial photographs from a fixed observation point permit determination of spot speeds for each of several lanes simultaneously, by the measurement of distances each vehicle travels in the time interval between two successive photographs. Results are subject to the same disadvantages as mentioned in the discussion of spot speeds.

The spaced serial photographic method may also be used from fixed elevated observation points at some locations to obtain traval times over short road segments of 200 to 1,500 ft in length, such as at the approach to an intersection (8). The time required for each vehicle to traverse the segment is obtained by counting the number of uniformly spaced exposures or "frames" which elapsed while the vehicle was within the segment of road. Normally, each frame is numbered so as to facilitate the determination of travel time for each vehicle. Results are limited by the shortness of the section, but are especially useful in studying travel time at weaving sections and at approaches to intersections (9).

Where the camera is used in conjunction with an aerial mount, such as a plane or helicopter, the height and focal length of the camera may permit a substantial length of street or highway to fall within the field of vision (8). In such a case, mean travel time may be determined from the photographic records by dividing the mean speed as obtained from successive pairs of photographs into the length of highway under study. Average travel times obtained by this method are accurate, but the technique has a number of disadvantages.

1. A considerable amount of preparatory work may be necessary in placing control markings on the highway. (In most urban work, however, street intersections, interchanges, etc., will generally afford sufficient control.)

2. The specialized flying equipment limits use of the method to those areas where such equipment is available.

3. The height of the camera is limited to that which will permit the identification of vehicles on successive photographs and as a result the field of view covered by the camera will include a relatively short section of street or highway.

4. Since the position of the camera is not fixed, it is difficult to maintain a particular section of highway within the field of view for any appreciable length of time.

5. Observations are limited to daylight hours with favorable atmospheric conditions.

6. Collection and transcription of data are more costly than is the case with some other of the several study methods.

Summary of Travel Time Techniques

Of the several techniques tested, only the spot speed method is of doubtful value in the determination of over-all speeds in urban areas. Even the spot speed method may have a particular field of usefulness and its possibilities have not been fully explored.

The recording of vehicle-license numbers and times is a practical method of determining mean travel times and over-all travel speeds for either low-volume or high-volume conditions. A sampling procedure, in which data for only one or two license-number endings are recorded for one hour, will normally be adequate for estimating the mean travel time for the entire hour within 5 percent under high-volume conditions. Under low-volume conditions, the number of license-number endings may be increased to provide an adequate sample for the hour of observations.

On streets with a relatively high percent of through traffic, the license-matching method is about as economical as any method and provides greater accuracy. When the percent of through traffic is low, the lengths of test sections must be short, thus increasing costs.

The test-car method affords an accurate means of obtaining average travel time on heavier traveled streets or highways, provided sufficient runs are made for each set of conditions being studied. The needed number of test runs is larger than is generally supposed. Accuracies within limits of less than 10-percent error are not feasible because of the excessively large number of test runs required. The "average" car method will yield results with a higher degree of accuracy than the "floating" method, for the same number of test runs on most types of street or highway. The test-car method may have an advantage in economy over the license matching method on long sections of street where large amounts of traffic turn off of or onto the section between the terminal points of the test section. The test-car method also has an advantage where the purpose of an investigation is to isolate the cause and extent of traffic delays throughout the length of a route.

The arrival-output method is suitable for determining the travel time on sections of highway where there are no access or egress points between the termini of the section. On that type of facility the method has an advantage in economy and accuracy over other methods.

The interview method is suitable where an approximation of travel rates based on peak-hour conditions over a short period of time is sought, or must be held acceptable in lieu of more comprehensive studies because of time limitations.

The photographic method is accurate but its use is limited to those areas where equipment is available. Where speeds or travel times during all hours of the day and under all types of weather conditions are sought, the photographic type of study must be supplemented by some other method or methods during hours of darkness and during periods of increment weather.

Time Mean Speed Vs. Space Mean Speed

Up to this point terms such as "average speed" and "average travel time" have been used rather loosely as though one might be readily converted to the other. Whether or not this can be done depends on the manner in which the average speed was obtained. As a simple example, if a test car should make two runs, the first at a speed of 40 mph and the second at a speed of 20 mph, the average speed would be 30 mph. If the length of course had been two miles, the first run would have required 3 minutes and the second run 6 minutes. The average travel time of 4½ minutes corresponds to an average overall speed of 26.6 mph.

In the first instance speeds for each individual test run were averaged. The terminology that has been applied to this type of result is, time mean speed. Time mean speed may be expressed as follows:

$$\text{Time mean speed} = \frac{\Sigma \frac{\text{distance}}{t}}{n}$$

where t is the travel time for each individual vehicle or each test run, and n is the number of such runs.

In the second instance the travel times for the individual test runs were averaged and a speed corresponding to this average travel time was calculated. Mean speed computed in this manner is termed, space mean speed, and may be expressed by the following equation:

$$\text{Space mean speed} = \frac{\text{distance}}{\frac{\Sigma t}{n}}$$

Space mean speed can be converted directly to average travel time; time mean speed cannot be readily converted. Time mean speed is always greater than space mean speed, and there is no simple means of converting one to the other.

Average spot speeds as usually expressed are time mean speeds. The license matching method, for example, produces space mean speeds. To compare results obtained by these two methods one must be converted so that both are on the same basis and this conversion is sometimes a tedious operation.

This discussion of alternate types of mean speeds might be perplexing to those seeking a simple method of obtaining mean travel time, and it might be of considerable interest to the more statistically minded. In any event the difference between the two types should not be ignored. To those who are not interested in the statistical implications it is helpful to remember that in most study methods the average travel time is obtained directly. Also, in economic investigations it is usually the difference in speed (travel time) between two different routes which is sought, or the difference in speed on the same route before and after an improvement or other change. In such a case the difference between the space mean speeds for the two routes is about the same as the difference between their time mean speeds. Hence it is relatively unimportant which type of mean speed is obtained so long as the same type is employed in both cases. The only real danger lies in the possibility that different types of speeds might be used in comparing mean speeds measured several years apart or by different investigators.

The subject of mean speeds is more fully discussed in Reference 6, pages 329-331.

OVER-ALL TRAVEL TIME ON A YEARLY BASIS

It has already been stated that economic investigations of road-user benefits are usually based on costs for a 1-year period. To be of any use in such investigations, travel time for any facility must likewise be computed on an annual basis. The committee has not extended its investigations beyond the development of study techniques, and there seems to be little information available from other sources that would be helpful in the expansion of data collected in a short study to an annual figure.

It is well recognized that the speed of traffic on any particular facility will vary from hour-to-hour, day-to-day, season-to-season, and so on. If the annual average travel time is to be determined by a sampling process, the causes for the fluctuation in speed must be isolated and factors must be developed for each cause so that the results of short studies can be brought into line with the annual average.

The number of variable conditions that affect the speed or travel time of traffic is almost limitless, but the ones having greatest effect are: (1) traffic volume in relation to the traffic-carrying capacity of the facility, (2) character of traffic, (3) weather, (4) accidents, and (5) traffic-control measures.

Effect of Traffic Volume on Speed

Where all other conditions remain unchanged and traffic volume alone is the only variable, the average speed of traffic on a particular highway decreases with an increase in

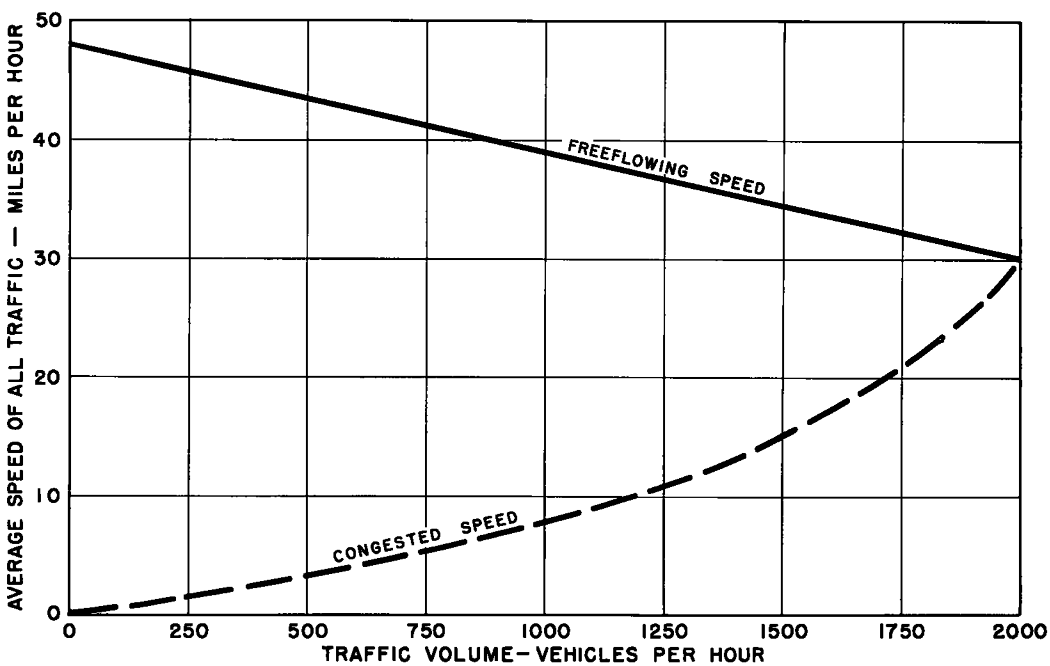

Figure 1. Relation between average speed of traffic and traffic volume on a 2-lane rural highway having a possible capacity of 2,000 vehicles per hour under favorable operating conditions.

volume. Extensive studies on rural highways have shown that, for short sections of highway at least, there is a straight-line relation between traffic volume and average speed where other conditions are identical and the critical traffic density is not exceeded (5). This relationship is believed to be true for any length of highway. The relationship can be very easily established for a particular section of street or highway by determining the average speed at a low volume and again at a high volume, but under free-flowing conditions in both cases and for the same character of traffic. The upper portion of the curve (unbroken line) in Figure 1 shows how the relation might appear for a facility where the flow is uninterrupted by traffic signals. When the volume of traffic becomes so heavy that it is equal to the possible capacity of the facility, however, a further increase in traffic demand will cause the average speed to decrease rather rapidly and this decrease in speed will be accompanied by a marked reduction in the volume of traffic that the facility can accommodate. This is shown by the lower portion of the curve (broken line) in Figure 1. This figure shows that for a traffic volume of 875 vehicles per hour, for example, the average speed of traffic might be 40 mph (under free-flowing conditions) or it might be 6.5 mph (under highly congested conditions). The average speed might be anywhere between these extremes, but it is likely to be somewhere along one or the other of the curves unless there is a change in conditions other than in traffic volume. Along the lower curve, however, the traffic volume, and hence the speed, may fluctuate very rapidly over a wide range.

Average speeds as represented in Figure 1 may be converted to average travel time to determine the variation of that element with traffic volume. This has been done in Figure 2. It will be noted that the travel time per vehicle increases tremendously after the traffic demand exceeds the possible capacity.

Information such as that shown in Figure 2 could be very useful in determining travel time on an annual basis if the data are complete to the following extent:

1. A separate curve can be prepared showing the relation between travel time and traffic volume for each of the other four conditions enumerated above, and for all combinations of these conditions.

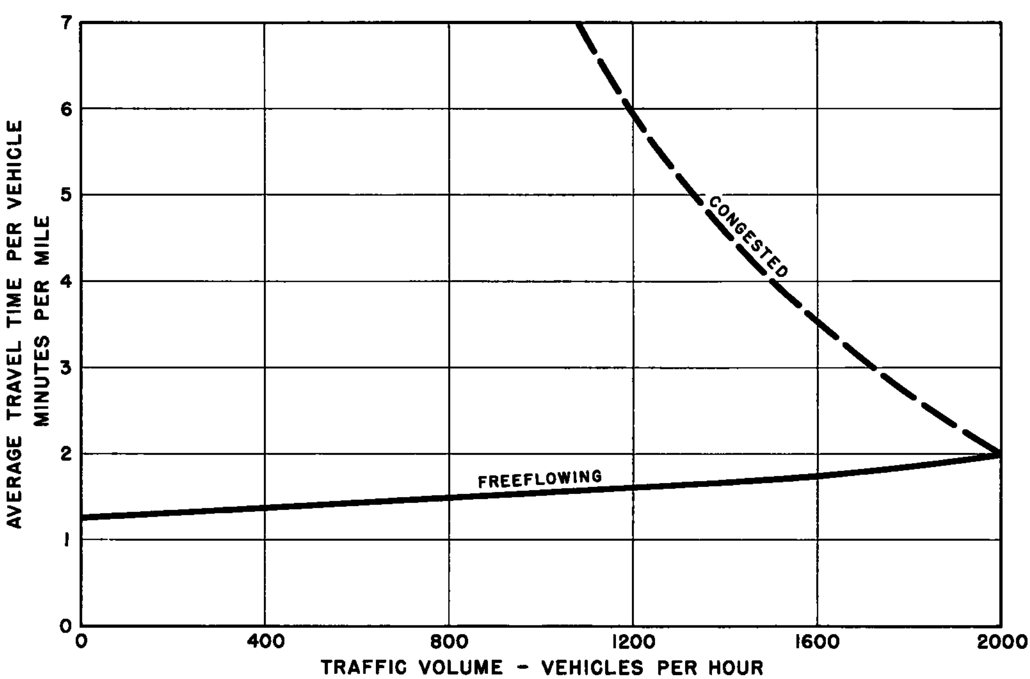

Figure 2. Relation between average travel time and traffic volume on a 2-lane rural highway having a possible capacity of 2,000 vehicles per hour under favorable operating conditions.

TABLE 5

YEARLY TRAFFIC PATTERN AND TOTAL YEARLY TRAVEL TIME ON A 4-MILE SECTION OF 2-LANE RURAL HIGHWAY

Example

Hourly traffic volume: Range	Hourly traffic volume: Average	Number of occurrences during year	Total vehicles during year	Travel time per vehicle-mile	Distance	Total travel time
Number	Number	Hours	Number	Minutes	Miles	Vehicle Minutes
0 - 99	50	1,185	59,250	1.26	4.0	298,620
100 - 199	150	1,400	210,000	1.28	4.0	1,075,200
200 - 299	250	1,445	361,250	1.30	4.0	1,878,500
300 - 399	350	1,260	441,000	1.33	4.0	2,346,120
400 - 499	450	1,085	488,250	1.35	4.0	2,636,500
500 - 599	550	895	492,250	1.38	4.0	2,717,220
600 - 699	650	680	442,000	1.41	4.0	2,492,880
700 - 799	750	495	371,250	1.45	4.0	2,153,250
800 - 899	850	285	242,250	1.48	4.0	1,434,120
900 - 999	950	29	27,550	1.51	4.0	166,402
1,000 and over	1,050	1	1,050	1.55	4.0	6,510
Total		8,760	3,136,100			17,205,322

Average travel time — 5.49 minutes per vehicle

2. The traffic volume during every hour of the year is known and can be classified as to whether traffic was free-flowing (upper curve, Figure 1) or was so congested that the critical density was exceeded (lower curve, Figure 1). It may be readily appreciated that in order to obtain this classification it might be necessary to keep certain congested sections of highway under almost constant observation and that a manual classification for congested conditions would be required. For this reason it is impractical to obtain the relation between travel time and volume on an annual basis on any except free-flowing facilities. Such facilities are not common in urban areas but it is seldom that rural highways become so completely congested that the critical density is exceeded.

Table 5 is an example of the manner in which the information in Figure 2 might be applied to determine the average annual travel time over a length of highway. In this analysis it was assumed that the conditions relative to weather, character of traffic, etc., did not change sufficiently throughout the year to affect the speed of traffic.

Effect of Character of Traffic on Speed

"Character of traffic" has reference to such items as purpose of trip, frequency with which the trip is made, length of trip, familiarity of drivers with the route, and other related matters as they pertain to a majority of the motorists using the particular route during the various hours of the year. Little research has been directed toward the effect that these characteristics have on the speed of traffic, but it is known to be rather marked. For example, where the traffic stream is largely composed of home-to-work traffic, it is apt to move more expeditiously, if traffic volume is taken into consideration, than is the case when the majority of motorists are shoppers or tourists. Likewise, Sunday afternoon pleasure drivers generally set a more leisurely pace than do daily commuters, and nighttime drivers generally operate in a manner differing from daytime drivers.

These variations in the character of traffic do not necessarily void the straight-line relation between speed and traffic volume. However, each of the several classes of traffic has a curve of its own, albeit a straight line, and the curves for all of these classes are approximately parallel.

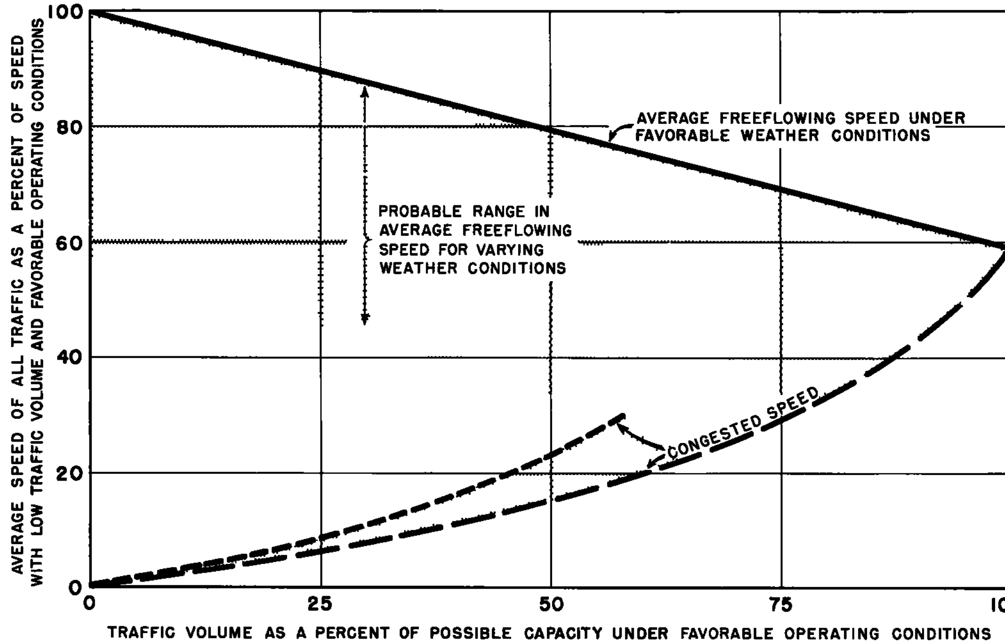

Figure 3. Illustration of probable effect of weather on the relation between average speed of traffic and traffic volume (not based on observed data).

The position of the lower portion (broken line) of the curve as shown in Figure 1 would remain substantially unchanged by a change in the type or character of traffic. The upper portion (unbroken line) of the curve would intersect the lower portion at a different point, depending on the character of traffic, and for this reason the possible capacity of the facility would vary with the character of traffic.

Effect of Weather Conditions on Speed of Traffic

Generally speaking, the effect of inclement weather is to lower vehicular speeds. Just how much the reduction in speed might amount to is dependent upon the severity of the weather. The reduction in speed would be felt throughout the complete volume range, from a few vehicles per hour up to the possible capacity of the facility. The relation between speed and traffic volume would again be a straight line, roughly parallel to and below the curve in Figure 1 which shows this relation for favorable conditions.

Unfavorable weather conditions tend to raise the lower portion (broken line) of the curve in Figure 1. Although not based on actual observation, Figure 3 shows the probable range within which the average free-flowing speed might vary with varying weather conditions. Because this is an hypothetical example of a highway with no specified capacity, values along the horizontal axis are expressed as percentages of the possible capacity of the facility rather than as absolute values. The average speeds along the vertical axis are treated in a similar manner. The lower limit of the shaded area in Figure 3 cannot be precisely located, and extremes of poor visibility (fog) or poor traction (snow or ice) may sometimes be accompanied by even more drastic reductions in speed than are suggested by the graph.

When weather conditions are abnormally severe, the possible capacity of a facility may be only a fraction of its full capacity under favorable conditions. Traffic demand, or the number of vehicles desiring to use the facility, may be reduced only slightly by the abnormal weather, however. Under such conditions the relation between speed and volume would be as shown by the lower portion (broken line) of the curve for severe weather in Figure 3. Both the speed and traffic volume would be very low. Travel time per vehicle would be increased several fold and, because of the reduced capacity,

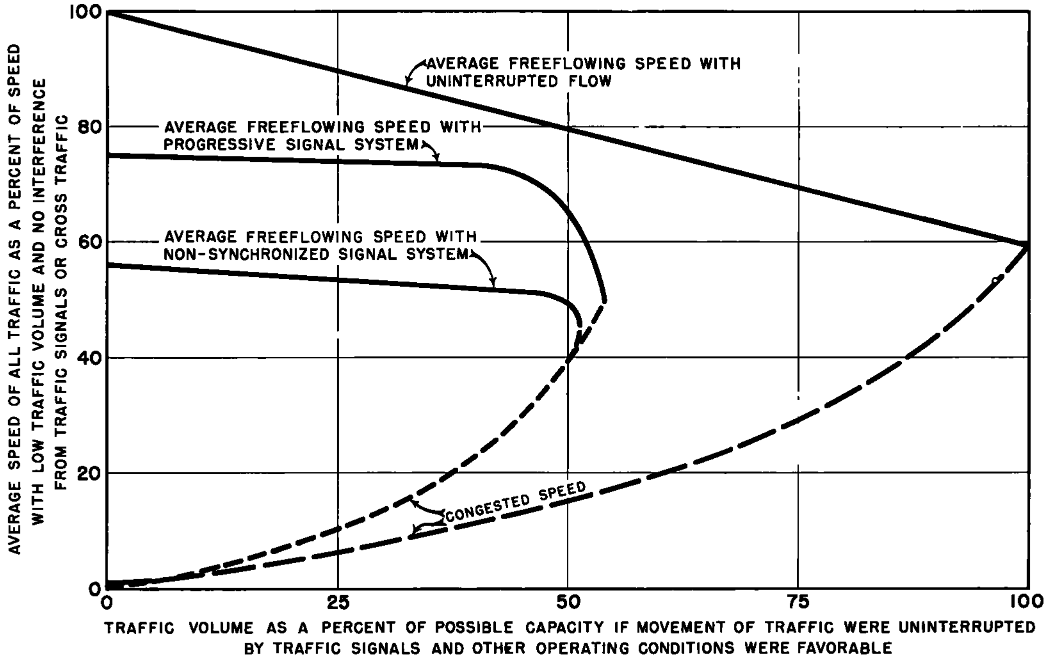

Figure 4. Illustration of probable effect of traffic signals on relation between average speed of traffic and traffic volume (not based on observed data).

several hours might be required for the facility to discharge the number of vehicles that ordinarily would be handled in a much shorter period of time.

Effect of Accidents on Speed of Traffic

Accidents or disabled vehicles are frequently the cause of serious traffic delays. Just how extensive the delay may be depends largely on the severity of the accident, the traffic volume in relation to the capacity of the facility at the time, and the period of time required to remove disabled vehicles. On uncongested facilities the delay caused the average motorist by even a rather serious accident may be negligible. On facilities carrying near-capacity loads, the mere presence of a parked vehicle can cause a complete stoppage of traffic. Oftentimes the stoppage is a direct result of traffic slowing to a speed below that at which the facility can accommodate the volume of traffic desiring to use it.

Effect of Traffic-Control Measures on Speed of Traffic

Traffic-control measures may be divided into two categories: first, those that remain unchanged in their operation or exercise of control from one period of the day to the next, and second, those that vary from hour to hour or from day to day. An interconnected system of traffic signals operating 24 hours per day on a fixed cycle might be an example of control measures in the first category. Signals operating on a varying cycle, signals operating on a part-time schedule, and police-officer direction of traffic are examples of the second category. The effect of traffic-control measures on the average speed of traffic depends upon which of the categories is involved. Those measures falling in the first category will cause little variation in speed from one period of the year to the next, whereas those in the second category might cause a very wide and unpredictable variation.

The effects that traffic signals may have on the speed of traffic can be so widely varied between different facilities and types of signal systems that it is futile to consider any single set of signals as being typical of all such installations. Figure 4 shows three type-curves for different conditions and is merely for the purpose of illustrating the nature (not the extent) of the variations in speed that might result from various types of installations. The item of greatest significance which these curves are intended to illustrate is that where traffic is controlled by signals and the possible capacity of the facility has been reached, there may be a wide range in average over-all speed with very little change in traffic volume. The reason for the almost perpendicular drop in the speed curve in Figure 4 is that the possible capacity of the facility is governed by the capacity of the intersections. When the capacities of the intersections are reached, queues of waiting vehicles will form, thereby increasing delay and travel time. The volume of traffic passing the intersections will not change appreciably until the queues become so long that no more storage space exists between intersections. When that condition occurs, both average speed and traffic volume will approach zero, following the course of the lower (broken) portions of the curves in Figure 4. Traffic volume cannot be used as an index of travel time on a signalized street unless the volume is always less than the possible capacity of the street. Also, for traffic volumes below practical capacities and where conditions other than traffic volume remain unchanged, there is little variation in travel time with changes in traffic volume.

Scheduling of Speed Studies

Any sampling technique in which use is made of short-period speed studies for determining average travel time on an annual basis must take into consideration the effect of the five variables discussed above, both singly and in combination one with the others. If precise results are sought, travel-time studies should be so scheduled as to include a complete range in traffic volumes for every condition and combination of conditions of weather, character of traffic, and traffic control normally expected during the year on the facility under investigation. To expand the results of these travel-time studies, a record would be needed of the number of hours of the year during which each set of conditions was effective. Also, for each traffic volume rate, it would be necessary to obtain the free-flowing speed and the speed for completely congested conditions, if complete congestion is experienced. The assembly of such detailed information is within the realm of possibility but would be regarded by most as being entirely impracticable. It is obvious that accuracy must be sacrificed for simplicity if a workable scheme is to be devised.

In seeking a practical sampling technique, the greatest handicap faced by the committee has been the lack of a known annual average travel time for a facility which might be used as a control for checking an expanded study sample. The determination of a true annual average travel time is regarded as so tedious and costly an operation that it is questionable whether it is worthwhile that it be accurately determined on any facility, even to satisfy research needs. Hence, any recommendation as to the scheduling of tests to produce a representative sample must be based, for the present at least, upon common judgment.

Because of the existence of significant variations in speed characteristics throughout the year, a minimum schedule should sample speeds during the seasons of the year, and, during each season, a normal working day and a week end. To sample properly the speed of traffic for any one day, the 24-hour period should be divided into several shorter periods during each of which the various elements that affect the speed of traffic remain substantially unchanged. For example, a knowledge of local conditions on a particular facility might suggest the following subdividions for a working day, Monday through Friday: A.M. peak 7:00 - 9:30, midday base 9:30 - 4:00, P.M. peak 4:00 - 6:30, evening 6:30 - 12:00, night 12:00 - 7:00.

Saturday and Sunday should likewise be divided into a minimum number of periods during each of which the character and volume of traffic, and traffic-control measures, remain essentially constant. Holidays might be classed as Saturdays or as Sundays, depending upon the similarity of conditions.

There is no reason to think that speeds during the various periods of a day need all be sampled on the same day. Tests for the 7:00 - 9:30 period, for example, might be made on a Tuesday (or they might extend over several days), and for the 4:00 - 6:30 period on Wednesday of the week following. A minimum schedule for a season, March through May, might be as shown in Table 6.

TABLE 6

SCHEDULE OF TRAVEL-TIME STUDIES FOR ONE SEASON OF A YEAR

Example

Period sampled		Hours included	Date and hour of study
Type	Period of day		
Working day	A.M. peak	7:00 - 9:30	Tuesday, March 27, 8:00 - 9:00
	Midday base	9:30 - 4:00	Tuesday, March 27, 10:30 - 11:30
	P.M. peak	4:00 - 6:30	Thursday, April 12, 5:00 - 6:00
	Evening	6:30 - 12:00	Wednesday, April 18, 8:00 - 9:00
	Night	12:00 - 7:00	Thursday, April 19, 1:30 - 2:30
Saturday (or holiday)	Forenoon	8:00 - 12:00	Saturday, April 7, 9:30 - 10:30
	Afternoon	12:00 - 5:00	Saturday, April 7, 2:00 - 3:00
	Evening	5:00 - 12:00	Saturday, April 7, 10:00 - 11:00
Sunday	Early morning	12:00 - 9:00 a.m.	Sunday, May 6, 7:00 - 8:00
	Late morning	9:00 - 1:00 p.m.	Sunday, May 6, 12:00 - 1:00
	Afternoon	1:00 - 7:00	Sunday, March 18, 3:00 - 4:00
	Evening	7:00 - 12:00	Sunday, May 20, 10:00 - 11:00

A schedule along the general line of the above example should also be prepared for the other three seasons of the year. The schedule should be modified in the event abnormal conditions prevail on the date tests are scheduled; however, attempt should be made to include within the tests a sample of weather conditions in the degree that these conditions occur throughout the year. Extremes in weather that occur only once or twice a year should be disregarded.

The travel time obtained during each time period appearing on the schedule is representative of the travel time for a certain segment of the yearly traffic. The average travel time for the year is the average of the results of the various tests, weighted according to the number of vehicles per year which use the facility during each of the time periods of the year represented in the schedule.

The committee can offer no assurance that a schedule prepared in the suggested manner will furnish accurate results for all types of facilities. However, for streets that are seldom or never loaded to their possible capacity, the results obtained would doubtless be within the limits of accuracy of the field testing procedure employed. On facilities where the traffic demand is often in excess of the possible capacity of the street, as evidenced by frequent delays of unpredictable duration, a much more extensive test program than that suggested must be scheduled. Travel time mounts very rapidly under the conditions last described.

It is extremely doubtful that a satisfactory procedure can be developed for estimating an average travel time for some year in the future. At such time in the future as the volume of traffic has reached the possible capacity of the facility, traffic will either divert itself to other facilities (thereby upsetting traffic forecasts) or travel time will soar Also, the possible capacity of a facility is sensitive not only to changes in weather conditions and characteristics of traffic but to physical changes to the facility or in the traffic-control devices employed. The first two factors named may not change appreciably from year to year, but our more congested facilities are undergoing almost constant change either in their physical dimensions or in the measures used to control and regulate traffic. However, for the solution of specific present-day problems, some of the methods described may find useful application.

DEFINITIONS

Spot speed. A spot speed is the speed, in mph, of a vehicle as it passes a given location on a street or highway. The term "average speed" denotes the mean speed of spot speeds for a specified period of time.

Travel time. The total time required to traverse a given distance, including all traffic stops and delays. (May also have "average travel time")

Over-all speed. The total distance traversed, divided by the total travel time, expressed in mph.

Average over-all speed. The average of the over-all speeds of all vehicles on a given roadway during a specified period of time.

Over-all travel speed. The speed over a specified section of highway, being the distance divided by over-all travel time. The average for all traffic, or component thereof, is the summation of distances divided by the summation of over-all travel times.

Time-mean speed. The averages of spot speeds or over-all speeds.

Space-mean speed. The speed corresponding to the average travel time over a given distance.

Volume. The number of vehicles moving in a specified direction or directions on a given lane or roadway that pass a given point during a specified period of time, viz., hourly, daily, yearly, etc.

Density. The number of vehicles occupying a unit length of the moving lanes of a roadway at a given instant. Usually expressed in vehicles per mile.

Critical density. The density of traffic when the volume is at the possible capacity on a given roadway. At a density either greater or less than the critical density the volume of traffic will be decreased. Critical density occurs when all vehicles are moving at or about the optimum speed.

Possible capacity. The maximum number of vehicles that can pass a given point on a lane or roadway during one hour, under the prevailing roadway and traffic conditions.

Practical capacity. The maximum number of vehicles that can pass a given point on a roadway or in a designated lane during one hour without the traffic density being so great as to cause unreasonable delay, hazard, or restriction to the drivers' freedom to maneuver under the prevailing roadway and traffic conditions.

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THE NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL is a private, nonprofit organization of scientists, dedicated to the furtherance of science and to its use for the general welfare. The ACADEMY itself was established in 1863 under a congressional charter signed by President Lincoln. Empowered to provide for all activities appropriate to academies of science, it was also required by its charter to act as an adviser to the federal government in scientific matters. This provision accounts for the close ties that have always existed between the ACADEMY and the government, although the ACADEMY is not a governmental agency.

The NATIONAL RESEARCH COUNCIL was established by the ACADEMY in 1916, at the request of President Wilson, to enable scientists generally to associate their efforts with those of the limited membership of the ACADEMY in service to the nation, to society, and to science at home and abroad. Members of the NATIONAL RESEARCH COUNCIL receive their appointments from the president of the ACADEMY. They include representatives nominated by the major scientific and technical societies, representatives of the federal government, and a number of members at large. In addition, several thousand scientists and engineers take part in the activities of the research council through membership on its various boards and committees.

Receiving funds from both public and private sources, by contribution, grant, or contract, the ACADEMY and its RESEARCH COUNCIL thus work to stimulate research and its applications, to survey the broad possibilities of science, to promote effective utilization of the scientific and technical resources of the country, to serve the government, and to further the general interests of science.

The HIGHWAY RESEARCH BOARD was organized November 11, 1920, as an agency of the Division of Engineering and Industrial Research, one of the eight functional divisions of the NATIONAL RESEARCH COUNCIL. The BOARD is a cooperative organization of the highway technologists of America operating under the auspices of the ACADEMY-COUNCIL and with the support of the several highway departments, the Bureau of Public Roads, and many other organizations interested in the development of highway transportation. The purposes of the BOARD are to encourage research and to provide a national clearinghouse and correlation service for research activities and information on highway administration and technology.