# Speed and Travel Time Measurement in Urban Areas

## WILLIAM P. WALKER, Chairman Highway Transport Research Engineer, Bureau of Public Roads

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 speedmeasuring 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.

<u>Arrival-Output Volume Rate Method</u>. This method is adaptable to the controlledaccess 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.

<u>Ground or Air Photographs</u>. 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 twolane 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.

The saving in man-hours through use of a sampling procedure is very much worthwhile. On many streets, one person at

TABLE 1

NEEDED FOR DETERMINING MEAN OVER-ALL SPEEDS ON VARIOUS TYPES OF FACILITIES WITH AN ERROR NOT TO EXCEED 5 PER- CENT 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	

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 manhours 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 manhours 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" testcar 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.

### 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:

#### 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 maxi- mum 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	

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

Example				
License number	Time of	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	3:58	
		-8:02:43		
Difference		3.58		

TABLE 3

## DETERMINATION OF AVERAGE TRAVEL TIME BY LICENSE MATCHING METHOD

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 co-operation of strategically located firms or establishments should be obtained as a pre-liminary 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

		EX	ampie		
5	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 2 3 4 5 6 7 8 9 10 11 12 13 14 15	26 35 31 39 26 33 29 37 24 28 38 35 30 27 19	$\begin{array}{llllllllllllllllllllllllllllllllllll$	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	25 30 32 36 40 31 26 24 29 27 33 36 40 28 20	$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$
(35 seconds) Total	457	3,327.2	(21 seconds)	457	3, 388. 5
Average		$3,327.2 \div 457 = 0:07:17 + 8:30:00 8:37:17 -$			$3,388.5 \div 457 = 0:07:25 + 8:30:55 8:38:20$

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  $4\frac{1}{2}$  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:

Time mean speed = 
$$\sum_{n=1}^{\infty} \frac{\frac{\text{distance}}{t}}{n}$$

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:

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

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





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 freeflowing 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 freeflowing 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.





#### TABLE 5

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

Example

Hourly traffic volume		Number of occurrences during	Total vehicles during	Travel time per vehicle-	Distance	Total travel
Range	Average	year	year	mile		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	<b>895</b>	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	<b>2</b> 85	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

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 davtime 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,



TRAFFIC VOLUME AS A PERCENT OF POSSIBLE CAPACITY IF MOVEMENT OF TRAFFIC WERE UNINTERRUPTED BY TRAFFIC SIGNALS AND OTHER OPERATING CONDITIONS WERE FAVORABLE



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 - 6:30period on Wednesday of the week following. A minimum schedule for a season, March through May, might be as shown in Table 6.

#### TABLE 6

L'wom	2010
елани	ure

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

<u>Density</u>. 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.

<u>Critical density</u>. 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.

<u>Possible capacity</u>. 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.

<u>Practical capacity</u>. 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.

#### REFERENCES

1. American Association of State Highway Officials, "Road User Benefit Analysis for Highway Improvements, Part I," Washington, D.C., 1952.

 Berry, Donald S., and Green, Forest H., "Techniques for Measuring Over-All Speeds in Urban Areas," Highway Research Board, Proceedings, 1949 (pp. 311-318).
Sawhill, Roy B., "Travel Time Techniques on a Two-Lane Rural Highway," Insti-

3. Sawhill, Roy B., "Travel Time Techniques on a Two-Lane Rural Highway," Institute of Transportation and Traffic Engineering, University of California, Berkeley, California, January 1952.

4. Berry, Donald S., "Evaluation of Techniques for Determining Over-All Travel Time," Institute of Transportation and Traffic Engineering, University of California, Berkeley, California, January 1952.

5. Committee on Highway Capacity, Highway Research Board, "Highway Capacity Manual,"U.S. Government Printing Office, Washington, D.C., 1950.

6. Wardrop, John Glen, "Some Theoretical Aspects of Road Traffic Research," The Institution of Civil Engineers, London, Proceedings, June 1952, Part II.

7. Association of Casualty and Surety Companies, "Manual of Traffic Engineering Studies,"60 John Street, New York City, 1953.

8. Forbes, T.W., and Reiss, Robert J., "35-Millimeter Airphotos for the Study of Driver Behavior," Highway Research Board, Bulletin 60, 1952 (pp. 59-66).

9. Berry, Donald S., and Vantil, C.J., "An Evaluation of Methods for Measuring Delay at Intersections," California Street and Highway Conference, Berkeley, Proceedings, 1954.