attained for the next 10- or 15-yr. period by the efficient use of the existing street facilities.

Recommendations based upon the conclusions of the evaluation of the urban-highway routes have been accepted by municipal governments as an action program which will, directly and indirectly, provide immediate reliefs to the transportation network deficiencies. Such progressive action has been taken by Washington cities as restriction of curb parking, prohibition of left and U-turns, revision of the arterial-street network, inauguration of one-way-street systems, application of the principles of speed zoning, provision of effective lane width, installation of pedestrian-protection devices less restrictive to vehicular movement than traffic signals, and the establishment and improvement of bypass routes. Other effective administrative steps taken by local officials towards solution of the traffic problem have been· modernization of city traffic ordinances, centralizing all traffic-engineering functions in smaller towns under the office of city engineer, adoption of national sign standards, establishing standard school-safety-patrol practices and planning long-range-improvement programs.

The highway department's share in improving urban-highway-route deficiencies found by the evaluation process has been achieved by such engineering activities as: the designing and installation of progressive-signal systems, signing of one-way-street systems, the increasing of the capacity of two-way streets by prohibition of turns and revised signal timing where requests for one-way systems were found to be inappropriate, resurfacing of rough roadways, planning of alternate urban-highway routes, and cooperating with municipal officials on development of a master plan for the long-range construction of adequate traffic facilities.

The results of the urban-highway-route evaluation have, therefore, been effectively employed in two ways. First, they have provided a sound basis by which municipal officials can recognize the extent of their traffic problems and take steps to alleviate the conditions by planning traffic-improvement programs. Second, the evaluation process has provided the factual data necessary to assist the Department of Highways to fulfill its obligations in municipalities by establishing priority in the programming of urban projects for improvement.

EVALUATION OF TECHNIQUES FOR DETERMINING OVER-ALL TRAVEL TIME

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SYNOPSIS

AS A CONTINUATION of an earlier investigation (*1*), field tests were made on signalized streets in urban areas to compare techniques of determining over-all travel time through use of test cars. The techniques used in operating the test cars were: (1) The "floating-car" method, in which the driver is instructed to "float" with traffic, and to pass as many cars as pass him; and (2) "Average" test runs, in which the driver is instructed to travel at a speed which, in his opinion, is representative of the speed of all traffic at the time without reference to keeping a balance in the passings.

As an aid in evaluating the two different methods, the actual travel times of vehicles passing both ends of the test section were determined by recording vehicle-license numbers of each vehicle and the times they passed each end of the test section.

The results revealed that both of the test-car driving techniques produced average over-all travel times which were close to the average travel times as obtained through the license-check method. The average-test-run results for multilane streets showed somewhat less dispersion than the results for the floating-car method, indicating that the same reliability of results could be obtained with the average-test-run method through fewer test-car runs than with the floating-car method.

Data on travel times and on over-all speeds, as obtained by license-number recording, were also analyzed for both rural and urban test sections. Mean over-all speeds can be determined with lower limits of error when using the license-matching method than when using a limited number of test cars. For most heavily traveled sections of street or highway, the recording of data for a sample of one or two license-number endings will provide an adequate sample for a study of at least an hour's duration.

●THIS STUDY is a continuation of a study of techniques for determining vehicle travel time reported at the Highway Research Board in December, 1949 (*1*). This earlier study concluded that the operation of test cars in the traffic stream is a practical method of measuring over-all travel times on important signalized streets in urban areas. The report recommended, however, that additional studies be made to determine the differences in results obtained by using the standard floating-car technique as compared with the use of the average-test-run method. The report recommended also that studies be made to evaluate the techniques of measuring travel time on nonsignalized streets and highways.

TABLE 1

URBAN TEST COURSES

Condition	Ashby Ave. (Acton to Hillegass)	San Pablo Ave (West to Haskell)
Length	1.45 miles	2.41 miles
Widths	42′ (3500′) 56′ (900′) 48′ (3256′)	73 ft.
Moving lanes (each dir.)	One	Three
Parking	Both sides	Both sides
Intersections	17 Eastbound 22 Westbound	32 Southbound 37 Northbound
Signals	5	5 (one is three-phase)
Average signal spacing	1425 ft.	1980 ft.
Traffic volume (off-peak)	440 veh. per hr. Eastbound 430 veh. per hr. Westbound	790 veh. per hr. Northbound 900 veh. per hr. Southbound
Traffic volume (P.M. peak)	880 veh. per hr. Eastbound 600 veh. per hr. Westbound	1570 veh. per hr. Northbound 1150 veh. per hr. Southbound
Train crossings	One train crossing	Two train crossings

This report describes results of investigations which were made for the two following purposes: (1) To determine, for signalized urban streets, the differences in results obtained with two different techniques of test-car operation—the standard floating-car technique as compared with the average-test-run method; and (2) To make a preliminary investigation of the feasibility of different methods for obtaining travel times for rural highways.

This study is one part of the research program suggested by the Committee on Operating Speeds in Urban Areas of the Department of Traffic and Operations, Highway Research Board. The committee has as its final objective the development of a sampling technique whereby average travel speeds of traffic on highway facilities can be measured on an annual basis with a reasonable degree of accuracy.

PROCEDURE

Urban Study—In the urban phase of the study, sections of two streets, approximately 1½ to 2½ miles in length, were selected as test sections. Four test cars were driven over each test section, each test car making at least three round-trips each hour. Each driver used a different driving technique on each successive round-trip during each hour. The driving instructions corresponded with the following two driving techniques:

Floating-test-car run—the driver is to "float" with traffic, and pass as many vehicles as pass the test car.

Average-test-car run—the driver is to travel at a speed which, in his opinion is representative of the speed of all traffic at the time, without trying to keep a balance in the number of passings.

Observers were stationed at each end of a test section to record the license numbers of vehicles as they passed each end of the section. Stopwatch times were also recorded; watches at the two ends were synchronized to permit determination of travel times for vehicles passing through the test course. License numbers and times were recorded by voice on battery-operated disk-recording machines.

Automatic-recording traffic-volume counters were used to record traffic volumes continuously at 15-minute intervals.

Test Courses—Two test courses were selected as representative of two widths of major signalized streets in urban areas. Data in respect to each test section are given in Table 1. A brief description of each test course follows:

Ashby Avenue—Ashby Avenue is a major street crossing the southern part of the City of Berkeley, extending from the East-Shore Freeway to the eastern city limits. The 1.45-mile test section contains five traffic signals, with an average spacing of 1,425 ft. In general, the street accommodates one moving lane of traffic in each direction, with some parking on both sides at all times.

San Pablo Avenue—San Pablo Avenue is a major street extending from downtown Oakland, through the western part of Berkeley, to Richmond. The 2.41-mile test section is located in the City of Oakland, with secondary business development along both sides of the street. The street is of sufficient width to permit parking on both sides, with three moving lanes of traffic in each direction. There are five signals in the test section.

Data are also included for tests made on Broadway in Oakland. Broadway is approximately 70 ft. wide, with parking, and has seven signals in the 1.5-mile test section. Other data on this test section are given in a previous report (*1*).

Rural Study—In the rural study, three sections of heavily-traveled state highway in California were selected as test sections as follows:

1. Two-lane section of US 40 south of Fairfield This 3.6-mile section of 22-ft. pavement is relatively level, and free from sight-distance restrictions Traffic volumes in vehicles per hour for the study periods were as follows: July 9, 1,080 total, with 570 westbound; August 20, off-peak, 1,130 total with 550 westbound; peak, 1,440 total, with 950 westbound.
2. Four-lane divided highway with control of access, on US 40 northwest of Fairfield, adjoining the two-lane portion described above. Each roadway has 12-ft. lanes, wide shoulders, and no sight-distance restrictions.
3. Three-lane section of State Route 24, west of Walnut Creek. This 4.73-mile test section passes through Lafayette. The pavement width was 32 ft., with 7-ft. shoulders. Two traffic signals are included in the section. This section later was reconstructed to a four-lane, undivided highway, with 10-ft. lanes, and 3-ft. shoulders.

License-check studies were made on each of the three sections to determine travel times for peak and off-peak traffic conditions. In

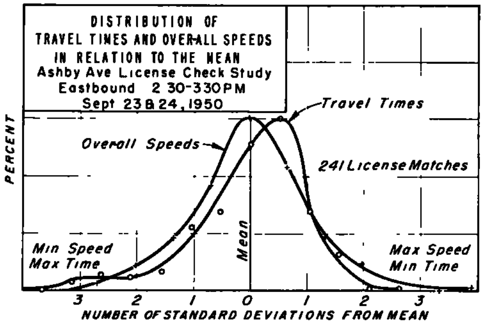

Figure 1

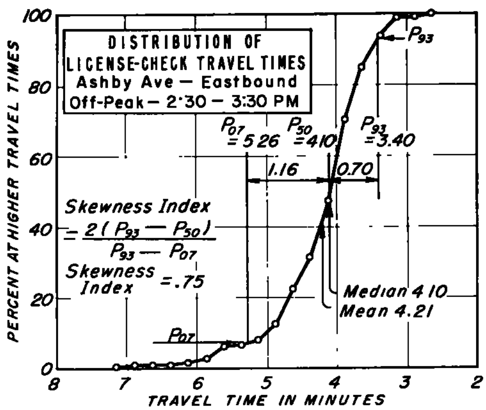

Figure 2

some of the license-check studies travel times were sampled by recording data only for vehicles with license numbers ending in 0 or 4. Test cars were also operated on the two-lane sections. Spot speed studies were made on both the two-lane and the four-lane divided sections of US 40.

PRESENTATION AND ANALYSIS OF DATA

Travel Times versus Over-all Speeds—The license-check studies have provided data for comparing the distributions of travel times with the distributions of over-all travel speeds for different highway and traffic conditions.

Figure 1 shows a comparison of the distributions of travel times and over-all speeds for traffic on Ashby Avenue during non-peak traffic-volume conditions. The over-all speeds were computed by converting the corresponding travel times which were obtained in the license-check study. The distributions are plotted in relation to the number of standard deviations from the mean.

A symmetric distribution would have a skewness index of 1.0, since the ninety-third and the seventh percentile values are equally distant from the median value. In this example, the skewness index is 0.75, indicating that the travel-time distribution is heavily skewed toward the longer travel times.

Table 2 presents data on the distributions of travel times and over-all speeds for license-check studies made on several sections of urban street and rural highway under different traffic volume conditions. The table includes data from tests previously reported (*1*, *2*, *3*) as well as including data from tests reported here for the first time.

TABLE 2
DISTRIBUTIONS OF TRAVEL TIMES AND TRAVEL SPEEDS
As Obtained by the License-Check Method

Street, Direction and Test Conditions	License Number Endings	Number of Cases	Travel Times in Minutes			Travel Speeds in MPH		
			Mean	Std. Dev.[a]	Skewness Index[b]	Mean	Std. Dev.[a]	Skewness Index[b]
Urban Test Sections								
1. Ashby, eastbound, off-peak	all	241	4.21	0.64	0.75	21.1	3.0	0.98
2. Ashby, westbound, off-peak	all	221	4.41	0.69	0.69	20.1	2.6	0.87
3. Ashby, eastbound, peak	all	752	5.04	0.77	0.85	17.6	2.7	1.08
4. Ashby, westbound, peak	all	463	4.73	0.64	0.85	18.7	2.6	1.03
5. San Pablo, northbound, off-peak	all	215	8.30	1.88	0.54	18.2	3.7	0.84
6. Broadway,[c] off-peak	0 & 5	249	5.64	1.42	0.59	16.8	3.8	0.92
7. Broadway,[c] peak	0 & 5	231	7.29	1.87	0.90	13.2	3.4	1.25
Rural Test Sections								
8. Two-lane,[d] 1080 vph	all	615	5.02	0.51	0 85	43.6	4.3	0.95
9. Two-lane,[d] 1130 vph	0 & 4	129	5.23	0.65	0.81	42.0	5.3	1.01
10. Two-lane,[d] 1440 vph	0 & 4	129	6.90	1.01	1.25	31.9	5.2	1.44
11. Four-lane,[e] off-peak	0 & 5	271	9.37	1.38	0.58	49.4	6.7	0.76
12. Three-lane, eastbound, peak	all	430	8.09	0.73	0.91	35.4	3.2	1 04

[a] Standard deviation estimated from percentile values for cases 6, 7, and 11.
[b] Computed from percentile values using the formula:

$$\text{Skewness Index} = \frac{2(P_{93}\text{-}P_{50})}{P_{93}\text{-}P_{07}}$$

Values below 1.0 indicate skewness toward longer times or slower speeds.

[c] Based on data reported first in References 1 and 2 of list of references at end of paper.
[d] Based on data reported in Reference 3 of list of references.
[e] Based on data reported in Reference 2.

It is readily apparent from Figure 1 that the distribution of over-all speeds conforms more nearly to a normal statistical distribution than does the distribution of travel times. The travel-time curve is skewed toward the longer travel times.

Figure 2 shows the travel-time data for this same series of tests on Ashby Avenue, plotted as a cumulative distribution curve. The skewness of the travel times toward the longer times in shown also on this curve. A skewness index has been computed in terms of the percentile values P_{93}, P_{50}, and P_{07}, utilizing the following formula (*2*).

$$\text{Skewness Index} = \frac{2(P_{93} - P_{50})}{P_{93} - P_{07}}$$

The table shows that travel-time distributions for off-peak traffic volume conditions are skewed toward the longer travel times. The distributions of over-all travel speeds more nearly approach normal curves. Their skewness indices are nearer to 1.0 than are the skewness indices for travel times.

Travel-time distributions for peak traffic-volume conditions tend to be more nearly normal than for nonpeak conditions for most of the test sections. The travel-time distributions at peak conditions for Broadway (Case 7) and for the two-lane rural test section (Case 10) are more nearly normal than their corresponding over-all speed distributions. Traffic volumes on both of these test sections approached possible capacity during the peak hours studied.

Case 11 in Table 2 represents the westbound roadway of a four-lane divided highway on US 40. The four-lane highway feeds traffic into the two-lane roadway represented by Cases 8, 9, and 10. Traffic on the four-lane highway flows freely, with ample opportunities for passing, and the resulting distributions of both travel times and travel speeds are skewed toward the longer travel times and slower speeds. When this same peak-hour traffic travels on the two-lane highway, with little opportunity for passing, as is the condition for Case 10, the mean speed drops materially, and the distribution curve for travel speeds becomes heavily skewed toward higher speeds.

Figure 3 shows a comparison of the over-all speed distributions for the two-lane highway under the two traffic-volume conditions of Cases 8 and 10. During the peak hour of 5 to 6 P.M., most of the vehicles are in platoons as they pass through the test section, and must travel at speeds fixed by the slower moving vehicles which lead the platoons. The skewness toward the higher speeds is readily apparent. At lower volumes, with more opportunities for passing the curve tends to be nearer a normal distribution.

It is easier to draw valid conclusions on such matters as the limits of error in the mean and on sample size when the statistical studies are made in terms of a variable whose distribution is approximately normal. Hence, for nonpeak traffic conditions, travel-time data should usually be converted to over-all speeds for analysis purposes. For certain peak conditions, however, travel times are preferable to over-all speeds.

A rough check of the travel-time versus over-all speed distributions for each case will quickly indicate which is more nearly symmetric, and which should probably be used in making the statistical computations. In this

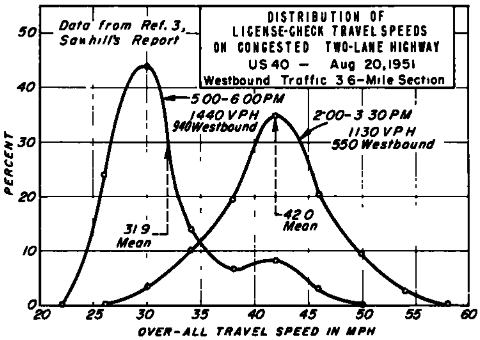

Figure 3

TABLE 3
LICENSE-CHECK TRAVEL TIMES VERSUS TEST-CAR TRAVEL TIMES

Test Location and Conditions		Test Method	Number of Cases	Travel Time in Minutes: Mean Time	Percentile Times: 50%	15%	85%	Standard Deviation of Sample
Ashby, off-peak, 2:30–3:30 P.M., Sept. 23 & 24, 1950	(1)[a] eastbound	License check	241	4.21	4.10	4.81	3.64	.64
		"Average" test car	16	3.95				48
		"Floating" test car	16	3.97				69
	(2) westbound	License check	221	4 41	4 28	4 86	3 83	69
		"Average" test car	16	4.27				.38
		"Floating" test car	16	4.29				.30
Ashby, peak-hour, 4:30–5:30 P.M., Sept. 23, 24 & 25, 1950	(3) eastbound	License check	752	5.04	4.93	5.83	4.32	.77
		"Average" test car	24	5.15				.72
		"Floating" test car	24	4.96				.77
	(4) westbound	License check	463	4.73	4.68	5.40	4.15	.64
		"Average" test car	24	4.84				.50
		"Floating" test car	24	4.88				.59
San Pablo, off-peak, 2:00–4:00 P.M., Feb. 9, 1950	(5) northbound	License check	215	8.30	7.87	10.23	6.70	1.88
		"Average" test car	10	7.39				.34
		"Floating" test car	11	7.15				.61
	southbound	"Average" test car	11	7.22				.52
		"Floating" test car	11	7.28				.82

[a] See Case No. 1 of Table 2 for other data on this series of tests.

paper, data are summarized in terms of both travel times and over-all speeds.

Average versus Floating Test-Cars in Urban Areas—Table 3 summarizes data on travel times as obtained by license checks and test

TABLE 4
LICENSE CHECK TRAVEL SPEEDS VERSUS TEST-CAR TRAVEL SPEEDS

Test Location and Conditions		Test Method	Number of Cases	Travel Speeds in M.P.H. Mean Speed	Percentile Speeds 50%	15%	85%	Standard Deviation of Sample
Ashby, off-peak, 2 30–3:30 P.M., Sept. 23 & 24,	(1)[a] eastbound	License Check	241	21 1	21 2	18.1	24 0	3.0
		"Average" Test Car	16	22 3				2.7
		"Floating" Test Car	16	22 5				3.5
	(2) westbound	License Check	221	20 1	20.3	17.9	22.7	2.6
		"Average" Test Car	16	20 5				2.0
		"Floating" Test Car	16	20 3				1.5
Ashby peak hour 4:30–5·30 P.M., Sept. 23, 24, 25, 1950	(3) eastbound	License Check	752	17.6	17.6	14.8	20 2	2.7
		"Average" Test Car	24	17 2				2 5
		"Floating" Test Car	24	18.0				2 8
	(4) westbound	License Check	463	18 7	18 6	16.1	21.0	2.6
		"Average" Test Car	24	18.2				1.8
		"Floating" Test Car	24	18 1				2.3
San Pablo off-peak 2:00–4:00 P.M., Feb. 9, 1950	(5) northbound	License Check	215	18 2	18 4	14.2	21 5	3.7
		"Average" Test Car	10	19 6				0 9
		"Floating" Test Car	11	19 9				1 8
	southbound	"Average" Test Car	11	20 1				1.4
		"Floating" Test Car	11	20 1				2.3

[a] See Case No. 1 of Table 2 for other data on this series of tests.

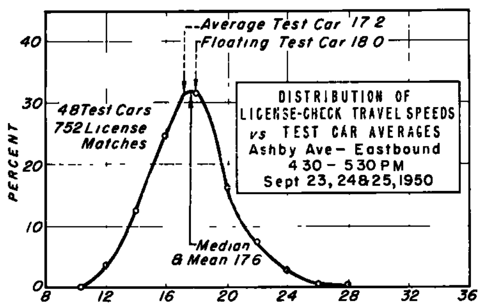

Figure 4

cars on Ashby and San Pablo Avenues. Table 4 presents the same data summarized according to over-all travel speeds for each of the test sections. The tables include mean and median values, the fifteenth and eighty-fifth percentiles, and the standard deviations of the samples taken for each test section.

Figure 4 shows graphically the test results for eastbound traffic on Ashby Avenue during the peak hour of 4:30 to 5:30 P.M. on each of the three days. The curve shows the distribution of travel speeds from the license-check study. The mean travel speed is 17.6 mph. The median speed is also 17.6 mph.

The chart also shows the average values of travel speed for 24 average test-car runs and 24 floating-car runs. The mean speed for average test drivers was 17.2 mph.—a little below the mean speed for the license-check study of all vehicles passing through the test section. The mean speed for the floating-car runs was slightly higher than the average for the license-check study.

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, as shown in Tables 3 and 4 The only exception is for San Pablo Avenue, where test-car methods yielded travel times 11 to 14 percent shorter than the license-check method. This is due in part to the distribution of license-check travel times for San Pablo Avenue, which is heavily skewed toward longer travel times. The mean test-car travel times were closer to the median value of the license-check travel time for San Pablo Avenue.

Test-car runs should produce more compact distributions than license-check distributions, since test-car drivers are consciously trying to approximate the predominating speed of traffic. On Ashby Avenue, however, the standard deviations for test-car runs are almost as great as those for the distribution of all the traffic checked in the license-number study. This may be due to the fact that traffic on Ashby Avenue travels in one lane in each direction most of the length of the test section, with little opportunity for passing. Consequently, a test car in a platoon of slow-moving vehicles stays with that slow platoon. The resulting dispersion of travel times for test cars thus would not be materially different than that for all traffic moving through the test section.

Figure 5 shows an example of the variations in individual travel times for vehicles passing through the test section on Ashby Avenue. Platoons appear to be moving through the section at different speeds, with the over-all speed of each test car corresponding to the speed of the platoon in which it is moving.

The standard deviations shown in Tables 3 and 4 reveal also that average test cars produce more compact distributions than do floating test-car runs. The differences are especially significant for test-car runs on the wider San Pablo Avenue, where test-car drivers have more opportunities for passing slower-moving vehicles. Thus, since the size of sample needed for specified limits of error is sensitive to changes in the standard deviation, it is apparent that fewer average test-car runs are needed for specified accuracy than are floating-car runs. The size of sample in relation to limits of error and the standard deviation is discussed in a later section of this paper.

Differences in Test-Car Drivers—Test-car run- were made by three experienced test-cas drivers on San Pablo Avenue during both offr peak and peak traffic conditions on several different days. The drivers each were given the instructions for average test-car runs. The drivers started their test runs approximately one minute apart in order that the drivers would make their runs under comparable traffic conditions.

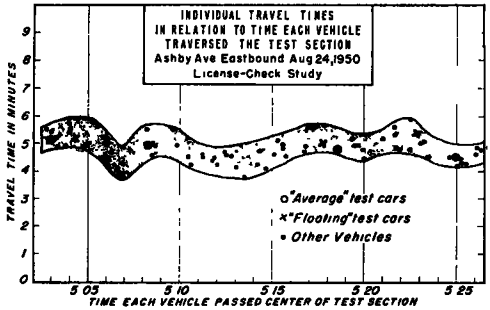

Figure 5

TABLE 5
OVER-ALL SPEEDS OF THREE TEST-CAR DRIVERS

Driver and Test Condition	Off-Peak 2:00–4:00 P.M. Number of Runs	Off-Peak Mean Speed, MPH	Off-Peak Standard Deviation, MPH	Peak 4·00–5:00 P.M. Number of Runs	Peak Mean Speed, MPH	Peak Standard Deviation, MPH
Northbound						
Driver A	13	20 2	1 4	13	17.5	1 6
Driver B	12	20 6	0.6	11	17 8	1 3
Driver C	13	20.0	0 8	12	17 7	1.9
Three drivers	38	20.3	1.0	36	17.7	1 6
Southbound						
Driver A	15	20.2	1.3	11	19.5	2 4
Driver B	14	20.0	1 0	10	19.4	1 9
Driver C	14	21.0	1.2	13	18.7	2.3
Three drivers	43	20 4	1 2	34	19.1	2.2

Results are presented in Table 5. These results are preliminary only, since only three drivers were used, and the tests were made on only one street. The data reveal, however, that the maximum difference between mean speeds obtained by the three drivers was 5 percent (for southbound, off-peak traffic conditions).

Earlier experience in selecting test drivers revealed that some test drivers tended to drive consistently faster or slower than other test drivers Use of such persons as test-car drivers should be avoided whenever possible.

Travel-Time Studies on Rural Highways—During the summer of 1951, studies of techniques for making travel-time studies in rural areas were undertaken by a University of California graduate student, Roy Sawhill, under the direction of the writer. Data were taken on the congested two-lane portion of US 40, with the assistance of staff members of the Institute of Transportation and Traffic Engineering of the University. Results have been reported in a Student Research Report (*3*) by Sawhill. Data in this section of this paper are based on tabulations included in Sawhill's report

Table 6 presents results obtained in Sawhill's study of license-check sampling on the congested two-lane highway on July 9, 1951. The table presents mean travel times for all license endings, and for each of the ten license-number endings separately, for three different study periods. The table reveals that any one of the ten license-number endings provided a sample which gave a good estimate of the travel time for all vehicles traversing the test section during the time period of the study. The maximum error for any sample was 2.2 percent.

TABLE 6

MEAN TRAVEL TIME BY LICENSE-NUMBER ENDINGS ON TWO-LANE HIGHWAY

License Ending	Study Period								
	8:45–10:15 A.M.			1:15–2:45 P.M.			5:00–6 00 P.M.		
	No of Cases	Mean Time, Minutes	Percent of Error	No. of Cases	Mean Time, Minutes	Percent of Error	No. of Cases	Mean Time, Minutes	Percent of Error
All numbers	550	5.04	0.0	619	4.99	0.0	707	5.41	0.0
0	58	4.98	1.2	65	5.06	1.4	79	5.43	0.4
1	58	5.15	2.2	59	4.99	0 0	45	5.41	0.0
2	60	4.99	1.0	58	4.98	0.2	58	5.49	1.5
3	50	5 02	0.4	71	4.94	1.0	71	5.46	0.9
4	56	4.94	2 0	62	4.99	0 0	67	5.40	0.2
5	49	5.11	1.4	53	5.09	2.0	74	5.47	1.1
6	51	5.07	0.6	60	4.97	0.4	54	5.38	0.6
7	61	5.04	0.0	62	5.00	0.2	79	5.45	0.7
8	55	5.06	0.4	55	5.07	1.6	78	5.32	1.7
9	50	5.12	1.6	69	4.92	1.4	76	5 34	1.3
"Red"[a] vehicles	13	4.84	4.0	31	5 00	0.2	21	5.32	1.7

[a] Red color of vehicle used in selecting sample for travel-time study.

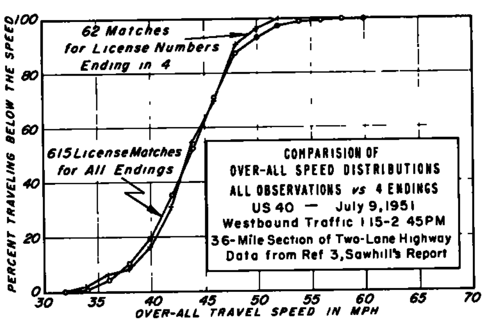

Figure 6

Figure 6 shows over-all speed distributions for traffic passing through the two-lane section during a nonpeak hour on July 9, 1951. One distribution represents the combined results of license matches for all ten license-number endings, while the other distribution is for license numbers ending in 4 only. The distribution of speeds of vehicles with license numbers ending in 4 is similar to the distribution curve for all vehicles.

License-check observers also recorded *red* vehicles separately when obtaining the data on license-number endings, which is given in Table 6. This table also shows the mean travel times obtained when red vehicles constituted the sample. The maximum error in the mean for the three samples of red vehicles was 4.0 percent. While the results obtained when using red vehicles as a sample are not conclusive, they do indicate the need for further study of vehicle color, location of radio antenna, or other distinctive feature in selecting a sample for license-check studies Use of vehicle color or other distinctive feature in selecting a sample would eliminate the necessity for scanning every license number when selecting samples of license-number endings.

Sawhill also collected data on test-car travel times, and on spot speeds of vehicles traversing the two-lane test section. Two test cars were operated during the time that license-check data were recorded manually for vehicle licenses ending in 0 or 4. Spot speeds were also taken for vehicles with licenses ending in 0 and 4. Results, in terms of speeds, are shown in Table 7.

The table reveals that mean speeds obtained by test cars were close to those obtained by the license-check method. The license-check method, however, provides much narrower limits of error, with a 95 percent degree of confidence, because of the larger size of sample. A license-check sample utilizing only one license-number ending would still provide lower limits of error than would results obtained with two test cars operating for the same period of time.

Two persons are required for license-check sampling for each direction of traffic on a two-lane highway when manual methods are used for recording data from one or two license-number endings. This is double the field personnel required for operation of two test cars. Office time for the license-check method in matching and computing travel times for samples with one or two digit endings varies with the traffic conditions but is usually about double the man-hours used in the field for obtaining the data[1]. Very little office time is required in reducing data for test cars.

TABLE 7

OVER-ALL SPEEDS AND SPOT SPEEDS FOR A CONGESTED TWO-LANE HIGHWAY

Traffic Volume Conditions	Test Method	Number of Cases	Mean Speed MPH	Median Speed MPH	Standard Deviation, MPH	Limit of Error in Mean,[e] MPH	Skewness Index[a]
Off-peak, 2:00–3:30 P.M.	License check[b]	129	42.0	42.0	5.3	±0.9	1.01
	Test cars[c]	13	42.1	42.3	4.5	±2.9	
	spot speeds[d]	125	41.0	41 3	7.6		1.00
Peak, 5.00–6:00 P.M.	License check[b]	129	31.9	30.6	5.2	±0.9	1 44
	Test cars[c]	8	31.9	30.2	5.9	±5.3	
	Spot speeds[d]	141	34.1	33.6	6.1		1 13

[a] A skewness index greater than 1.0 indicates skewness toward higher speeds.
[b] Over-all speeds obtained from matching licenses ending in 0's and 4's.
[c] Over-all speeds obtained by two "average" test cars.
[d] Spot speeds obtained at one location, using a 264-ft. trap, and recording speeds only for vehicles with licenses ending in 0 or 4.
[e] Limits of error computed for 95 percent degree of confidence.

[1] The time required in matching license numbers recorded at the two ends of a test section may be reduced by use of the following procedure: (1) License numbers for Station No. 2 are listed on a work sheet in columns, with each column containing only those license numbers corresponding to one license-number ending. (2) A license number for Station No. 1 is matched by scanning the numbers in the appropriate column of the work sheet for Station No. 2 and identifying the identical number. Use of 10 columns on the work sheet cuts the scanning time by about 90 percent.

Results of the spot-speed study for the peak hour are compared graphically with the distribution of over-all travel speeds in Figure 7. This spot-speed study produced a mean speed 2.1 miles higher than the mean for the over-all speed distribution. Both speed distributions are skewed toward the higher speeds, with over-all speeds more heavily skewed. The spot-speed study for the nonpeak period yielded a mean speed 1.0 mph. below that for the over-all speed as shown in Table 7. This spot speed was taken at the same location as the spot-speed study for the peak hour.

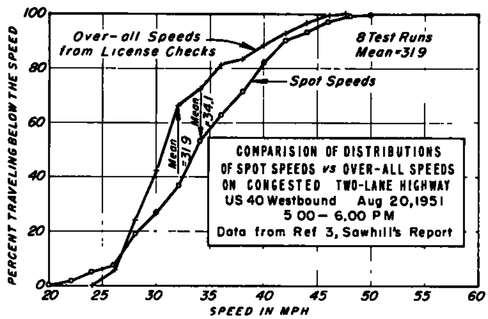

Figure 7

It is apparent that more study is needed of the use of spot speeds in estimating travel speeds for sections of highway. Spot speeds obviously would not provide a measure of over-all speeds for sections having traffic signals or other conditions which stop traffic. Spot speeds may be useful in predicting travel speeds for highways on which traffic flows without interruption. However, it should be kept in mind that even for freely flowing traffic, spot-speed distributions usually differ from the distributions of over-all speeds The differences are discussed in detail in an earlier report by Berry and Belmont (*2*).

Test-car runs have not been made on four-lane rural highways or on two-lane highways with traffic volumes below practical capacity. It is probable that test-car runs under such conditions would be less reliable in estimating the mean travel speed of all traffic, because of the greater difficulty in selecting a speed for test-car operation representative of all traffic at the time.

Size of Sample—In conducting test-car or license-number speed studies, the number of observations included in the sample affects the reliability of the resulting mean over-all travel speed or mean travel time. Limits of error for rural test sections, computed for 95 percent degree of confidence, are shown in Table 7.

It is possible, also, to compute approximately the minimum size of sample needed for determining mean over-all speeds within different limits of error, with a 95 percent degree of confidence. Such computations are necessarily approximate, because the standard deviation of the over-all speeds of the population being sampled is not known, and the standard deviation of a small sample is not a reliable measure of the standard deviation of the population

Table 8 presents the results of computations on size of sample, based upon approximations of the standard deviations of the populations. These computations furnish an indication of the sizes of samples needed for different limits of accuracy on test sections having characteristics similar to those listed in Table 8.

The table indicates that a sample of 32 license-check matches would be adequate in estimating the mean over-all speed for test conditions encountered on the uncongested two-lane street (Ashby Avenue, Cases 1 and 2 of Table 2), during the times of the study, within a 5 percent limit of accuracy, with a 95 percent degree of confidence. Table 2 shows that 241 license-check matches were actually obtained on this same uncongested street in an east-bound direction during the two hours of this study. Since *all* license-number endings were used in obtaining this sample, it is apparent that at least two license-number endings would be needed to obtain a sample of at least 32 license matches in a 2-hour study.

The actual sizes of the license-check samples for the other test sections reported in Table 2 have also been compared with the number needed for 5 percent accuracy, as given in Table 8. The comparison reveals that the studies for these other test sections were of sufficient duration so that use of a single license-number ending would have produced samples larger than the values set forth in Table 8.

TABLE 8
SAMPLES NEEDED FOR DETERMINING MEAN OVER-ALL SPEEDS ON SELECTED TEST SECTIONS WITHIN DIFFERENT LIMITS FOR 95-PERCENT DEGREE OF CONFIDENCE

Test Section[a]	License-Check Studies			Test-Car Runs		
	Mean Speed, MPH	Standard Deviation, MPH	Sample Size for 5% Accuracy	Standard Deviation, MPH[b]	Number Needed for Accuracy of 5%	10%
Signalized Urban Streets						
1. Two-lane, uncongested	21.1	3.0	32	3.0	30	8
3. Two-lane, congested	17.6	2.7	36	2.7	40	10
6. Multi-lane, uncongested	16.8	3.8	80	1.8	18	5
7. Multi-lane, congested	13.2	3.4	102	2.2	50	13
Rural Sections						
9. Two-lane, 1130 VPH	42.0	5.3	25	5.0	25	6
10. Two-lane, 1440 VPH	31.9	5.2	41	5.2	42	11
11. Four-lane, uncongested	49.4	6.7	30	—	—	—

[a] The numbers refer to the case numbers listed in Table 2.
[b] These are estimated values of the standard deviation of the population. Most of the values are slightly higher than the standard deviations of the samples of test-car runs obtained in this study, in order to be on the safe side.

Table 8 also indicates that a relatively large number of test-car runs would be needed to permit estimating the mean over-all speeds of test cars within the 5 percent limit of accuracy. A 10 percent limit of accuracy is obtained with a more practical number of test-car runs.

It is recommended that preliminary studies be made for each street to be investigated for the first time, so as to determine the approximate percent of through traffic, and the probable spread in speeds and travel times. Such data can be used in determining needed size of sample, the number of license-number endings to be included in the study, the number of test-cars required, and the necessary duration of the study in order to obtain an adequate sample.

Another sampling problem is the selection of times for making travel-time studies which are representative of different traffic conditions. The sampling of travel times for each major traffic-volume condition should provide values which can be used in computing total travel time on an annual basis within a reasonable degree of accuracy.

CONCLUSIONS

License-Check Procedure—The recording of vehicle-license numbers and times is a practical method of determining mean travel times and over-all travel speeds of vehicles traversing the entire length of a test section.

For most sections of street or highway, the recording of data for one or two license-number endings will provide an adequate sample for a study of at least one hour's duration. The size of sample for desired limits of accuracy should, however, be determined from preliminary studies on each test section before deciding on how many license-number endings to include in the sample.

One person at each end of a license-check test section can observe license plates and manually record times and license numbers for a sample of one or two license-number endings for one direction of traffic on many sections of street or highway. When using the license-check procedure for heavy traffic on roadways with two or more moving lanes in one direction, a voice recording machine, or a second person, is usually needed at each license-check observation station.

Test-Car Procedures—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 heavily traveled two-lane rural highways. The probable error of the estimate is greater when using a limited number of test cars, than when using the license-matching procedure.

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 multilane streets, floating test cars produce results which are less reliable than the results obtained with the same number of runs of average cars.

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. The driver may mentally note the balance in the number of passings, but will not try to pass a vehicle every time another vehicle passes him.

Recommendations for Further Study—Additional studies should be made of differences in results obtained by different test-car drivers when following the same driving instructions.

Additional studies should be made of the use of color of vehicle or other easily-identified characteristic of vehicle in selecting samples for license-check studies of travel time.

Further studies should be made to determine the extent to which spot-speed data can be used to estimate mean over-all speed for free-flowing and congested highways.

Equipment should be developed for use in test cars to permit a test-car driver to record necessary data for speed and delay studies without the assistance of an observer.

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TRAVEL-TIME AND GASOLINE-CONSUMPTION STUDIES IN BOSTON

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SYNOPSIS

Travel-time runs were made over highways and streets which will be most affected by diversion of traffic to the Boston central artery (John F. Fitzgerald Expressway) now under construction. These runs were made as the before part of a before-and-after study of traffic conditions in the central business district, which is to be traversed by the new elevated highway.

Runs were made in different hours and on different days to obtain representative averages of weekday travel conditions as well as of conditions prevailing during hours of peak traffic flow. Runs were made over a number of routes with a test car equipped with statistical instruments developed by the Highway Research Board Committee on Motor Vehicle Characteristics for measuring speed, gasoline consumption, braking effort, engine torque, and throttle opening.

Considerable information was gained on the characteristics of general city driving. Average speeds on congested streets in downtown Boston were found to to range from 7 to 12 mph. with a low of 3 mph. on some streets in peak hours; average gasoline mileage on these streets varies from 9 to 13 mi. per gal. with a low of 5 mi. per gal. on some runs. At speeds below 10 or 12 mph., when the speed of traffic is controlled by congestion, a close relationship apparently exists between miles per hour and miles per gallon. This relation should be useful in estimating gasoline consumption on congested streets from the traffic speed without the use of a gasoline meter.

A comparison of travel times on city streets with those possible after the expressway is completed indicates that there should be an average saving in time of 4.5 min. per mi. of expressway by its use. Some sections will save as much as 8 min. per mi. Gasoline savings per trip over the expressway will average about 0.04 gal. per mi.; on some sections there will be no savings, and on others the savings will be as much as 0.10 gal. per mi. A forecast of probable savings on one 0.85 mi. section of the expressway indicates that in 1955 there should be an annual saving in time cost of $420,000 and in gasoline cost of $65,000 when time is evaluated at $1 per hr. and gasoline at 27 cents per gallon.

●During the months of July, August and September 1951 travel time runs were made over a number of important streets in downtown Boston and vicinity to obtain a record of travel conditions on them prior to the construction of the Boston Central Artery (John F. Fitzgerald Expressway). After the new highway is in service it is planned to repeat the tests to determine the influence of the new facility on the speed of city traffic and to appraise the benefits in time and fuel savings made possible by the expressway.

The study was undertaken as a joint highway research project of the Massachusetts Institute of Technology and the Massachusetts Department of Public Works.