Objective and Subjective Correlates of Expressway Use

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● THE task of the Detroit Metropolitan Area Traffic Study is to develop a master highway plan for the metropolitan area, including a network of controlled-access expressways. After the expressway network has been determined, the number of vehicles desiring to use each expressway section and interchange must be estimated. This is done by a method commonly termed "traffic assignment." Traffic assignment is the "estimated allocation" of traffic to a proposed highway facility. Traffic is usually allocated after an objective comparison of a route via expressways to a route via city streets, for a group of trips between two zones. Based on comparisons of time, distance or speed, a percentage of trips are assigned or allocated to the proposed expressway.

Traffic assignment serves several useful purposes. First, it provides a method of testing expressway proposals for their ability to serve the traffic needs of an area, and therefore, provides a basis for determining the best locations for expressways. Second, it answers questions regarding the geometric design of facilities, such as: How many lanes are needed? Where should interchanges be placed? How much capacity is needed to facilitate on and off movements? Finally, it provides a basis for a benefit-cost appraisal of a system and is a useful tool in setting construction priorities.

The purpose of this study was to develop a method for assigning traffic to a proposed expressway network in the Detroit Metropolitan Area. Basic data tabulations were obtained from studies of diversion to five expressways in four different cities throughout the United States. In addition, a diversion study was made for the Willow Run Expressway, serving Southwest Detroit, to determine the effect of the local conditions on diversion. Based on the data from these six expressways, the relation of expressway use to objective measurements of time, distance and speed were studied, both singly and in combination. A family of diversion curves relating distance ratio and speed ratio to expressway usage were developed and are presented as a simple and rapid yet accurate tool for use in assigning traffic to a proposed highway facility.

Using data from the Willow Run diversion study, the staff explored the reasons, attitudes and perceptions of drivers in choosing between an expressway route and city street route. It was reasoned that a better understanding of diversion curves and their proper application could be gained by a study of the subjective processes involved in the choice of a route.

METHOD OF ASSIGNMENT

Traffic-Assignment Research to Date

In 1950, the Highway Research Board summarized[1] the practices of the several states in assigning traffic to route proposals. These practices varied from that of using personal judgement, to methods involving measures of time, distance, and cost. No empirical formula had been devised and the analytical approaches were based on theory. There was an obvious lack of agreement as to any "preferred" method of assignment and many engineers indicated that they were not satisfied with the method adopted by their particular agency.

Since 1950, empirical studies of superior street usage have been made in some half-dozen cities in the United States. Tabulations of basic data were obtained from the studies of diversion to the following expressways: (1) Shirley Highway in Arlington, Virginia;[2] (2) Gulf Freeway, Houston, Texas;[3] (3) Willow Run Expressway, Detroit,

[1] Campbell, M. Earl, "Route Selection and Traffic Assignment", Highway Research Board Correlation Service, 1950.
[2] Trueblood, Darel L., "Effect of Travel Time and Distance on Freeway Usage", Bulletin 61, Highway Research Board, January 1952.
[3] "Traffic Assignment to the Gulf Freeway", 3-page bulletin with graph and supporting tabulation, Texas Highway Department, December 15, 1954.

Michigan;[4] (4) Alvarado and Cabrillo Freeways, San Diego, California;[5] and (5) Central Expressway, Dallas, Texas.[6]

The purpose of these studies was to obtain empirical data which could be used in developing diversion curves for use in traffic assignment. Basic data from each of the above studies were obtained by the Detroit staff for comparative purposes and for further study of the relation of expressway usage to objective measurements of time, distance and speed.

Generally, the use of a facility has been related to time or distance variables. Few attempts have been made to show expressway use as a function of two variables. However, this report presents expressway usage in relation to time and distance differentials combined, and distance and speed ratios combined, in addition to the usual comparisons of usage related to time ratio, time differential and distance ratio.

Curves showing the expressway usage for various time ratios are presented next.

Relation of Travel Time to Expressway Use

The most common method of presenting the relation of expressway use to travel time has been by travel-time ratio. The travel-time ratio is calculated by dividing the amount of time required to make a trip via an expressway by the time required for the same trip via the most favorable city street route. Figure 1 shows the percentage of trips via an expressway for various travel-time ratios as determined from several independent studies. The time measurements for these studies were based on: (1) total trip, in which travel time is measured for the entire trip between origin and destination, via the routes being compared, and (2) points of choice, where measurements are made only for that portion of the trip which is not common to both routes. Since a portion of the trip is left out in the point-of-choice analysis, any ratio of time, distance or speed will not be the same as that obtained by a total-trip method of analysis. However, since the portion which is left out is common to both expressway and city street route, differentials of time, distance or speed will be the same by both methods. The Shirley Highway, Dallas, and Willow Run measurements are for the total trip, while the other studies noted are by the point of choice method.

From Figure 1 it is seen that the time-ratio curves have the same general shape. However, the percent of use for a particular time ratio varies among the different expressways. For example, the use of expressways when time ratio is 1.0 (i.e., equal time via expressway and city street) ranges from 48 percent for the Shirley Freeway to 18 percent for the Willow Run Expressway. Thus, for trips having equal time via an expressway and a city street route, assignment by the Shirley curve would be almost three times as much as an assignment by the Willow Run curve. Even though the curves have the same general shape and they group fairly close together on the chart, assignments to a particular expressway using the different curves vary radically. Table 1 shows the results of assignment[7] to six expressways by three time-ratio curves. Assignments were made in turn to the Shirley, Alvarado, Cabrillo, Willow Run and Gulf Freeways, by using time-ratios developed respectively by the Shirley study, Willow Run study and by a third curve which is an average of the curves for which data were available.

Assignments to the six expressways by the Shirley curve, as shown in Table 1, varied from 97.1 percent of the observed volume on the Shirley Freeway to 156.3 percent of the observed volume for the Alvarado Freeway. Assignments to the same six expressways, based on the Willow Run time-ratio curve varied from a low of 56.1 percent of the observed volume using the Shirley Freeway to 97.7 % of the observed trips using the Avarado Freeway.

[4]Unpublished Study by the Staff of the Detroit Metropolitan Area Traffic Study, 1954.
[5]Unpublished Report by the Traffic Division of the California Division of Highways, 1954.
[6]Photostatic Copies of Tabulations for Central Expressway Study in Dallas, Texas, Texas Highway Planning Survey, May 14, 1952.
[7]Using the basic tabulations which were obtained from the various diversion studies, the volume of all zone to zone transfers assigned for various time ratios, as determined by the Shirley study, Willow Run study and an average of all studies, was compared to the volume of zone to zone transfers actually observed using the facilities for corresponding time ratios.

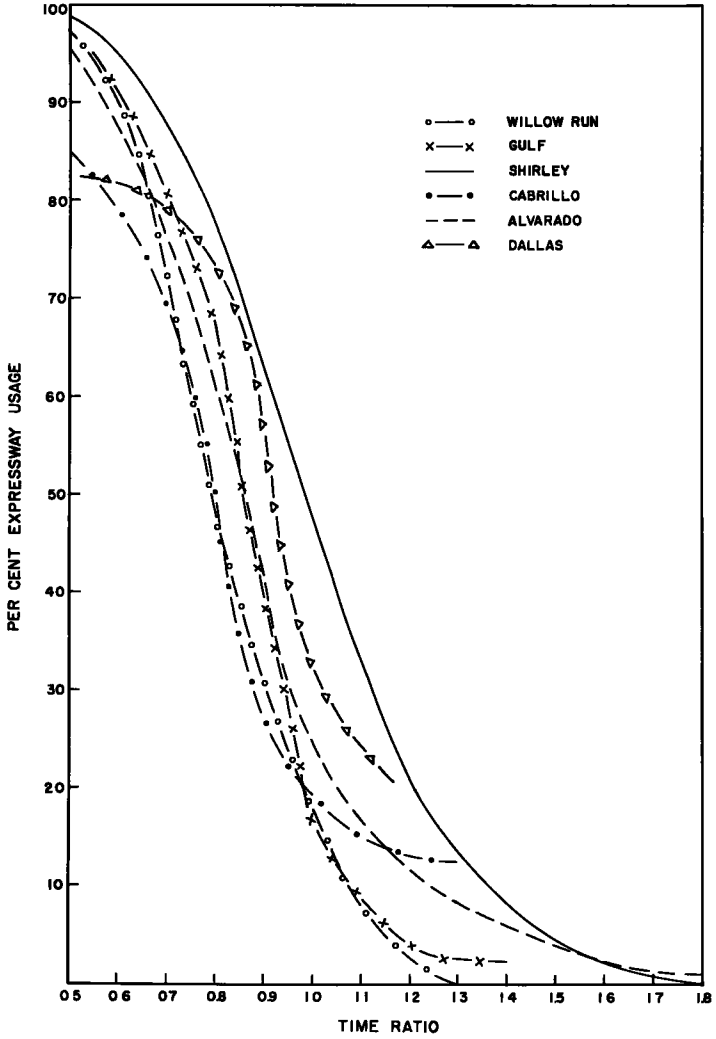

Figure 1. Expressway usage in relation to time ratio.

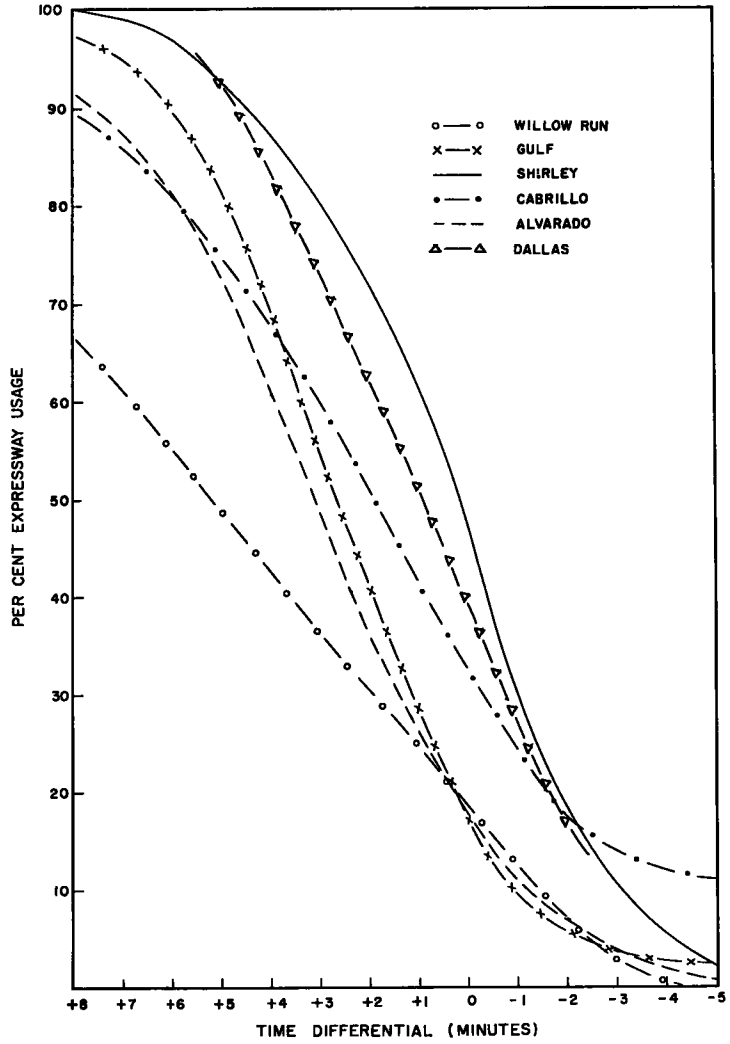

Figure 2. Expressway usage in relation to time differential.

TABLE 1

COMPARISON OF ASSIGNMENTS TO SIX EXPRESSWAYS USING THREE DIFFERENT TIME RATIO CURVES

Expressway	Assignment By: Shirley Curve % Total[a]	Shirley Curve St. Err[b]	Willow Run Curve % Total	Willow Run Curve St. Err.	% Average Curve % Total	% Average Curve St. Err.
		Percent		Percent		Percent
Shirley	97.1	± 3.5	56.1	± 18.5	74.2	± 11.7
Cabrillo	135.6	± 15.0	91.5	± 14.1	108.1	± 10.2
Alvarado	156.3	± 13.1	97.0	± 4.1	118.7	± 5.2
Willow Run	152.3	± 18.4	97.7	± 4.2	113.6	± 9.6
Gulf	142.2	± 15.6	81.9	± 14.1	105.3	± 12.1
Dallas	115.5	± 12.3	67.1	± 18.3	81.3	± 10.8

a Total assigned

b Total observed using expressway
Standard error is based on grouped data

Results of assignment by the average time ratio are shown in the last column in Table 1. Generally, the average curve does a better job than either the Shirley or Willow Run curve. However, for certain individual expressways a better assignment is obtained by use of the Shirley or Willow Run curves, as the case may be.

Why is there such a difference in expressway usage based on time ratio? If time ratio is to be used as a basis for estimating the use of a proposed facility, which curve should be used?

To answer the first question, data from individual expressways were examined closely. Average trip lengths, trip times, distance, time, and speed ratios were calculated for various expressways, in search of a clue which might help explain the variation in usage. These measures helped classify the different expressways as to the kind of trips which were being served, and the service the expressway afforded for the average trip. The various averages determined are summarized in Table 2.

Table 2 reveals a variety of trip lengths and times, speed and distance ratios, and other variables, thus indicating that all expressways are not serving the same type of trips and that some expressways offer more advantages than others. For example, the average trip length for Shirley Freeway users is 5.54 miles compared to 13.90 miles for the sample of Willow Run users. The average speed ratio for Shirley users is 1.17 compared to 1.40 for the average trip via the Willow Run Expressway. Similar comparisons can be made using other expressways or other average measures.

An actual case comparison at this point might help to point out the difference in expressways. This example will show how two expressways can logically have different usage for the same time ratio. At a time ratio of 1.0, i.e., equal time via expressway and city streets, the Shirley Expressway shows 48 percent usage and the Willow Run, 18 percent usage. For a trip of 6.0 miles, via the Shirley, the expressway driver must go roughly 20 percent further in using the expressway than the nonexpressway user to equalize times for the same trip. This is because, as speed ratio indicates, travel via the expressway is on the average 20 percent faster than via city streets. Thus, the Shirley user drives 6 miles compared to a 5-mile drive by the nonuser for the same trip. This is a difference of a mile, but as indicated, the travel times are equal. On the other hand, the Willow Run driver must drive 40 percent further in using the expressway to make the travel times equal for the expressway and city street routes, since his speed is on the average 40 percent faster than the speed for the nonexpressway trip. Therefore, he drives 14 miles in the same amount of time it takes to drive 10 miles via the city streets. Thus, a Willow Run user could go 4 miles out of his way to use an expressway, compared to one mile extra for the average user of the Shirley Freeway, when trave times are equal for the expressway and city street routes. This points out one difference in expressways and shows why diversion would not be expected to be the same for each expressway at a time ratio of 1.0. The factor which causes the difference in use of

TABLE 2

SHOWING AVERAGE MEASUREMENTS FOR SIX EXPRESSWAYS

	Shirley	Cabrillo	Alvarado	Gulf	Dallas	Willow Run
Average trip length[a]	5.54	5.10	8.45	5.95	4.19	13.9
Average distance gain via expressway	1.00	1.34	1.36	0.00	0.44	0.83
Average distance lost via expressway	1.27	1.50	3.04	1.40	0.74	2.82
Average trip time[a]	11.74	8.65	13.42	14.14	13.67	23.8
Average time gain via expressway	3.16	2.97	3.60	3.25	2.15	4.75
Average time lost via expressway	2.98	1.81	4.72	2.91	1.16	3.14
Average distance ratio	1.20	1.22	1.35	1.29	1.11	1.20
Average time ratio	1.08	0.90	1.11	1.03	0.87	0.88
Average speed ratio	1.17	1.35	1.28	1.26	1.29	1.40
Average speed for trip via expressway	28	35	37	25	24	35
Average speed for trip via alternate	24	26	29	20	19	25

NOTE: These measurements are averages only for those trips which fell in the samples for the various studies, and do not necessarily represent average values for all traffic on any particular expressway.

[a] Time is expressed in minutes, distance in miles.

individual expressways is, no doubt, the absolute difference in time or distance for transfers having the same ratios. The time-or-distance differential for any particular time ratio varies among different expressways, thus making an expressway more attractive or less attractive and causing differences in use for the same time ratio.

It should be remembered that these time-ratio curves are based on objective measurements of mass movement. The percent usage for any time ratio is a mean value and depends on the range and distribution of percentages of use for that particular time ratio. If all expressways served trips of the same length, had the same accessability, afforded the same speed, then, aside from subjective factors such as drivers' perceptions and attitudes, the usage as based on time ratio should be the same for all expressways. However, it has been pointed out earlier that these basic influence factors are not the same for all expressways; therefore, there is little reason to believe that the use should be the same for all expressways at the same time ratio.

The answer to the question raised earlier, as to which time-ratio curve should be used in assigning to a proposed expressway, is not simple. No single curve will be

suitable for all expressways. Therefore, the most-accurate assignment would result from a careful comparison and classification of the facility to be appraised with facilities from which time-ratio curves have been made and selection of a curve developed from the expressway most-closely resembling the facility to be appraised. The task of classifying a future expressway as to kind of trips which would use it and type of service it would provide is very difficult, if not impossible. For example, how can travel times be accurately estimated for some future period when it is difficult to measure them on existing streets? Nevertheless, some sort of classification is desirable in the choice of a time-ratio curve for use in a particular situation.

The fact that expressway use is not the same for all expressways at the same time ratio points out the need for some other tool which could be used to make assignments to any proposed facility. Apparently, at least two variables must be used to explain the variance in expressway use for particular time ratios. However, it is possible that summarizing expressway use by a single variable other than time ratio might combine trips in such a way that the resulting curves relating expressway usage and the variable being tested would be closer for the various expressways than the curves resulting from the time-ratio groupings. Therefore, expressway usage as related to time differential was explored and is presented next.

Expressway Usage as Related to Time Differential

Time differential is the absolute difference in time, stated in minutes, between a trip via expressway and city streets. A negative difference indicates a loss of time via the expressway. Regardless of the method of analysis, i.e., point of choice or total trip, the time differential is the same for any particular zone-to-zone movement.

Figure 2 shows the time-differential curves based on data from the various expressway studies. As in the case of time ratio, the curves have generally the same shape; however, the time-differential curves have a greater spread or scatter. Thus, a greater range in assignment would probably result by using the time-differential curves than with the time-ratio curves. This indicates the need for an even-closer examination and classification of expressways before selecting a curve and making an assignment based on time differential.

Figure 2 shows that when time differential was zero (time ratio equals 1.0) the usage varied from a low of 18 percent for the Gulf Freeway to a high of 48 percent for the Shirley Freeway. When 5 minutes could be saved via an expressway, the use varied from 49 percent as found for the Willow Run Expressway to 93 percent for the Shirley Freeway. The variation in speed ratios and trip lengths again offer logical explanations for the difference in usage of the various facilities. For example, a person can drive 3 or 4 miles out of the way in using the Willow Run Expressway and still save 5 minutes, due to the length of the trip and the possibility of travelling at a considerably higher speed while on the expressway. However, due to the short trips and lower ratio of speed between the Shirley and its alternate, a savings of 5 minutes is not physically possible, unless the trip via expressway is shorter than the trip via city streets. Therefore, a 5-minute time saving becomes much-more important to potential Shirley users because they save distance as well as time via the expressway.

For the Shirley Highway, the time-differential curve gave a higher correlation with expressway usage than the time-ratio curve. Trueblood[8] points out that the time-differential grouping tends to group zone-to-zone movements according to trip length and that this tendency results in a somewhat better correlation. Even though time differential gives a better correlation with the use of a particular expressway, it is apparent that absolute time savings do not provide the same attraction for all expressways. These differences apparently are due to the different trip lengths and speeds involved for the various expressways.

Assignment by the time-differential curves again involves an inspection and classification of expressways and then selection of an appropriate time differential curve. Therefore, the data were grouped by distance differential to see if this grouping would mini-

[8] Trueblood, Darel L., "Effect of Travel Time and Distance on Freeway Usage," Bulletin 61, Highway Research Board, January 1952.

mize the differences in the curves for the various expressways. The distance differential curves are presented next.

Expressway Usage as Related to Distance Differential

Distance differential is the difference in trip length between a trip via an expressway and via city streets. A negative differential indicates that the expressway route is longer than the city-street route.

Figure 3 shows the curves relating distance differential to expressway use for the Shirley Freeway and Willow Run Expressway. Only two of the curves were constructed, since it appears that distance differential has little value as a predictor of expressway usage. From the curves it is seen that the use of the Willow Run Expressway is four times as high as the Shirley for trips losing 3 miles and twice as great for the trips losing 2 miles. These curves are very steep and are, therefore, sensitive to small changes in distance differential. For example, when trip lengths are equal, 65 percent of the trips used the Shirley; however, the loss of a mile drops the expressway usage to 30 percent. This change of a mile on the distance differential scale has the effect of reducing the diversion by more than half.

TABLE 3

SUMMARY OF TEST ASSIGNMENTS TO SIX EXPRESSWAYS BASED ON DISTANCE RATIO

Expressway	Distance Ratio Curves Used in Assignments					
	Shirley Curve		Gulf Curve		Average Curve	
	% Total	SE[a]	% Total	SE	% Total	SE
		percent		percent		
Shirley	98.5	± 3.9	115.4	± 8.6	102.7	± 5.2
Cabrillo	90.7	± 11.5	107.6	± 11.8	95.9	± 11.1
Alvarado	97.4	± 4.6	119.1	± 7.5	104.4	± 4.6
Willow Run	90.9	± 11.0	120.5	± 11.6	104.5	± 10.5
Gulf	89.9	± 12.9	116.6	± 12.9	98.8	± 11.8
Dallas	85.7	± 18.2	102.0	± 14.3	89.0	± 22.2

[a] Standard error based on group data.

It would seem, therefore, that the percentage of expressway use is too sensitive to small changes in distance differential to be useful in traffic assignment.

Distance ratio was the final exploration made into the relationship of expressway usage to single variables. The distance-ratio analysis is presented next.

Relation of Expressway Usage to Distance Ratio

Distance ratio is the ratio of distance via an expressway to distance for the same trip via city streets. Figure 4 shows the percent of use for the various expressways, based on distance ratio. The curves fall close together on the chart, indicating that the range of assignments produced by these curves should not be great. For any distance ratio, the mean value of percentage use is close for all expressways.

When distance ratio is 1.0, indicating equal distances via the expressway and city streets, the use varies from 59 percent for the Shirley Freeway to 75 percent for the Willow Run Expressway. For distance ratios of 0.7 and less, 90 percent or more of the transfers were via the expressway for all the facilities studied. When the distance travelled by the expressway is 60 percent greater than the city streets, (i.e., distance ratio = 1.6) expressway use varied from 3 percent for the Willow Run Expressway to 16 percent for the Central Expressway in Dallas.

Table 3 is a summary of the results of assignment to the six expressways by three distance ratio curves. As in the case of time ratio, the curve which would produce the highest assignment (Gulf), and the one producing the lowest assignment (Shirley), and

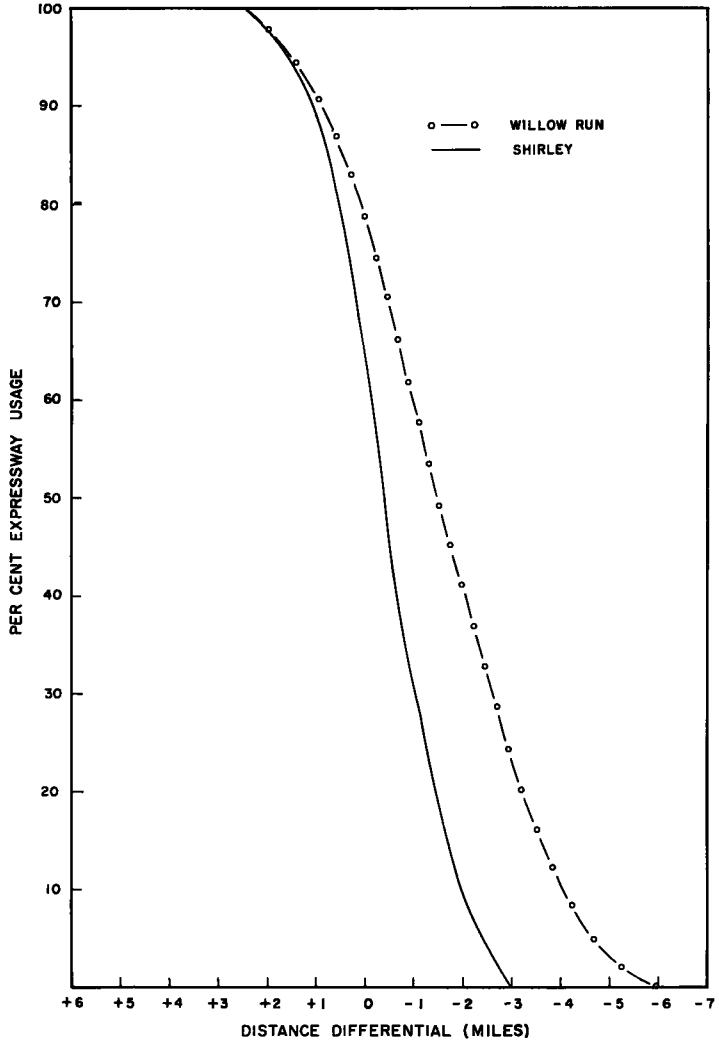

Figure 3. Expressway usage in relation to distance differential.

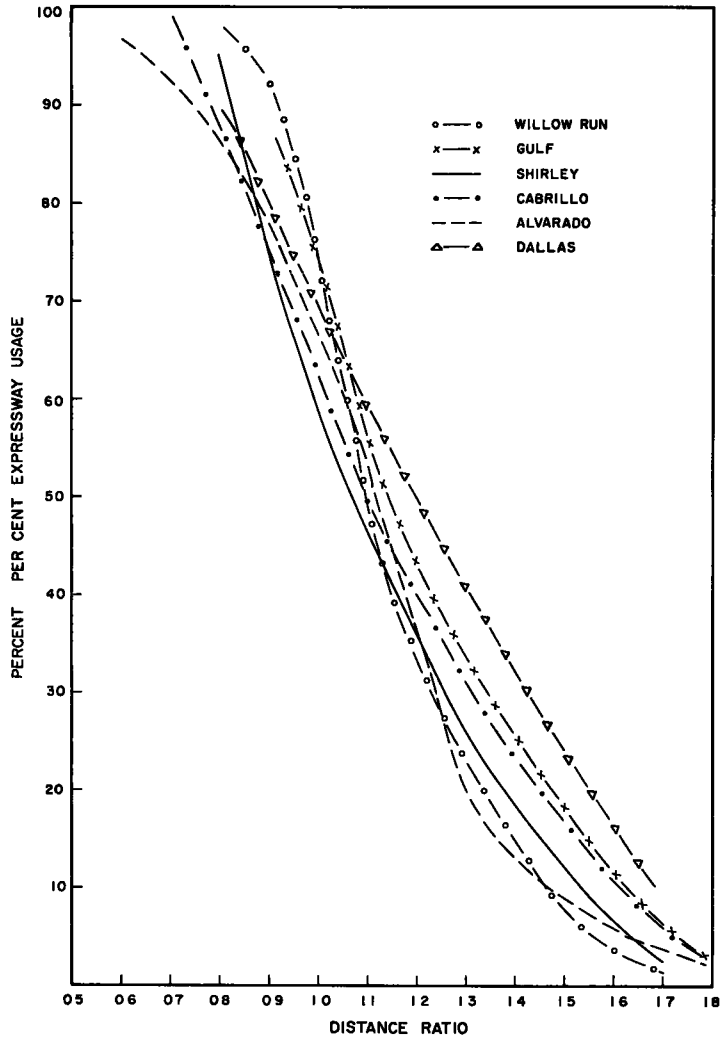

Figure 4. Expressway usage in relation to distance ratio.

a curve which represents an average of the distance ratio curves were used. The Shirley curve assigned 85.7 percent of the trips observed on the Dallas Freeway, and did a better assignment on the Shirley than to the other expressways with an assignment of 98.5 percent. The Gulf curve was consistently high in assignment. It assigned best to the Cabrillo with 107.6 percent of the observed volume and was highest for the Willow Run with 120.5 percent. The average curve assigned to all the surveys within 5 percent of the observed volumes, except the Dallas Expressway (which differed by 11 percent).

Trueblood, in his study of the Shirley Freeway, found that the points had a much-greater scatter when based on distance comparisons than on time comparisons. Because of this scatter of points, the standard error and statistical correlation for the Shirley Freeway were not as good for distance-ratio as for time-ratio comparisons. Generally, however, it appears that the factors which influence expressway usage are more-normally distributed when grouped by distance ratio than when grouped by time ratio; thus, although the scatter of points is greater, the group means for individual distance ratios are closer for all expressways than for time-ratio groupings. For expressways examined in this study, the total assignment was closer when based on distance ratio than when based on any other single variable. The average distance ratio curve assigned to five of the six expressways within 5 percent of the observed volumes using the expressways. Therefore, an assignment could be made to any of these expressways within tolerable limits, using the average distance-ratio curve, thus eliminating the need for classifying expressways in order to pick an appropriate curve.

Assignment by distance ratio probably would work, within tolerable limits, for any particular expressway, as long as the mean trip length and speed ratio fall within the range of trip lengths and speed ratios of the surveys shown in this study. For a single urban expressway, these average values would probably be close to those given in Table 2. However, for a network of expressways, longer trips via an expressway are possible and a greater portion of the trip can be made on an expressway, resulting in higher average speeds and greater absolute time savings for the expressway trip. Because of the higher speeds and greater time savings, the expressway usage would be higher than that shown by the average distance-ratio curve. Therefore, a system which would assign different percentages of trips for the same distance ratio depending upon the relative advantage of particular trips would be desirable. A set of curves based on two or more independent variables appears to be the solution.

The more variables that are used the more difficult it becomes to find the relation between the variables and the percentage of expressway use and, to apply the curves in an assignment problem. Therefore, curves employing only two independent variables were tested.

Aside from subjective influences, such as drivers' attitudes and perceptions, the factors which exert the most influence on a driver's choice of route appeared to be those of time, distance, and speed. Since these three variables are interrelated, curves using any two automatically control the third.

The next section of this report presents the relation of expressway usage to time and distance differential.

Expressway Usage as Related to Time and Distance Differentials

Time and distance differentials were selected because, regardless of the method of study, i.e., point of choice or total trip, they mean the same thing.

Figure 5 shows the relation between expressway usage and time and distance differentials. The curves were constructed empirically by averaging data for the Alvarado, Cabrillo, and Shirley freeways and showing on graph paper the average percent use for each combination of time and distance differentials. Using judgment, curves were smoothed by hand for each 10 percent of expressway usage, resulting in the curves shown on Figure 5.

These curves suggest that time saving can become more attractive or less attractive by varying the distance differential for the same time differential. As an example, for a time-saving of 2 minutes, with no distance loss, about 70 percent of the trips would be via an expressway; however, if 2 miles are lost in order to gain the 2 minutes, the use drops to slightly more than 40 percent. The same reasoning applies to the distance

differential. When distances are equal and times are equal, the expressway usage is 50 percent; however, when five minutes can be saved for equal trip lengths, the usage is over 90 percent.

The shape of the curves implies that, as the distance loss becomes greater, the loss looms more and more important to the user, and he must have increasingly greater increments of time gained in exchange for additional unit distance losses. The fact that the curves tend to approach the horizontal as use approaches 100 percent indicates that the rate of exchange of time for distance must become increasingly larger in order to cause an increase in the percentage use for the high percentage use range.

Test assignments were made to the Shirley, Alvarado, and Cabrillo freeways to see what percent of the observed volumes could be predicted by using the curves. Results of the assignment were 89.4 percent for the Shirley, 109.8 percent for the Cabrillo, and 118.0 percent for the Alvarado.

Even though distance-ratio curves assign to these three expressways within 5 percent of the total volumes observed, the standard error for ungrouped data is much higher for distance ratio then for time and distance differentials. Therefore, the error in assignment of individual transfers and, consequently, the error in expressway section and ramp volumes, would be less using the two variable assignment.

Despite the apparent value of the time and distance differentials in assignment, the application is very difficult, since it involves measurement of time for an expressway and city street route. Therefore, a two-variable curve which gives accurate results and, in addition, is simple to handle and easily adapted to mechanical methods of assignment would be desirable.

Expressway Usage as Related to Distance and Speed Ratio

Distance ratios are calculated in the same manner as stated earlier. Speed ratios are obtained by dividing the average speed for a trip via an expressway by the average speed for the same trip via city streets. The curves presented in this section were de-

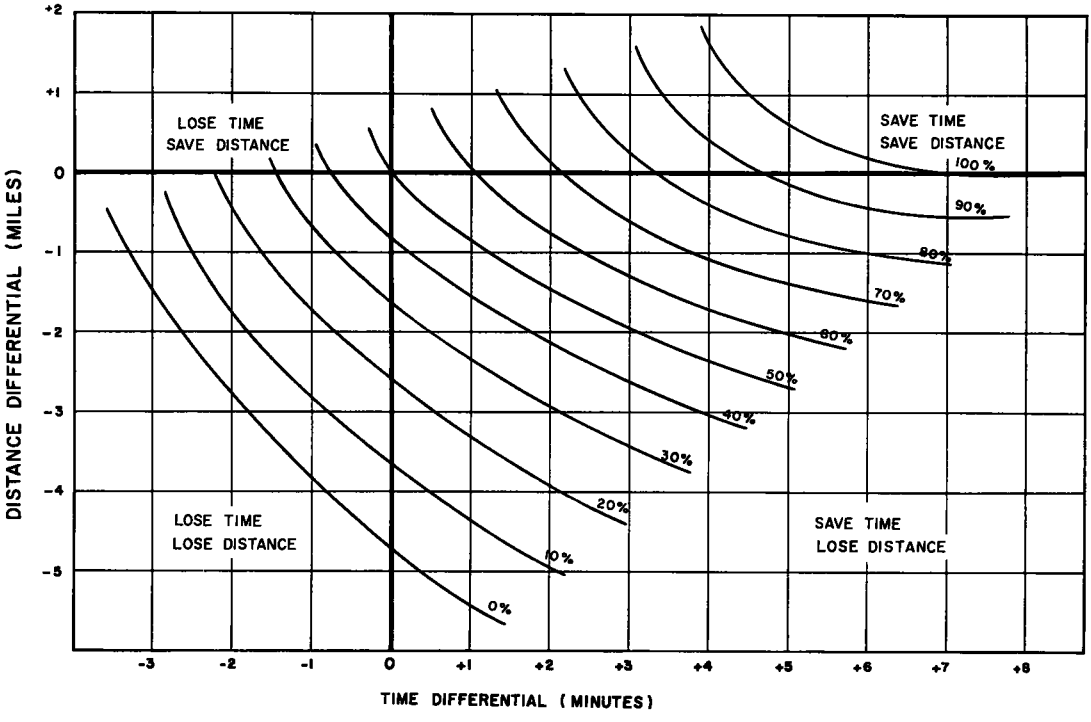

Figure 5. Indifference curves for various percentages of expressway use, based on time and distance differentials.

TABLE 4

REPORTED ADVANTAGES OF THE ROUTE CHOSEN

Advantage	Total	Expressway User	City Street User
Distance oriented advantages:	42	8	34
Shorter (more direct, straighter, less distance)	38	7	31
Nearest, nearest my home, closest route to my home)	4	1	3
Time oriented advantages:	33	26	7
Quicker-faster, save time (reason not given)	10	7	3
Quicker-fewer stops, stop streets, stop lights	13	11	2
Quicker-less traffic, congestion	6	6	-
Quicker-traffic moves faster, thru traffic	1	1	-
Quicker-can go at greater speed	1	1	-
Quicker-better road surface	2	-	2
Traffic and traffic movement:	17	7	10
Less traffic	8	2	6
Fewer stops, stop lights, stop streets, stop signs	7	4	3
Fast moving traffic, thru traffic, stop lights well timed	2	1	1
Road Characteristics:	4	-	4
Better, improved driving surface	2	-	2
Like width, number of lanes, left turn lane	1	-	1
Better road, driving (unspecified)	1	-	1
Miscellaneous	9	1	8
Easier driving - fewer stops	1	1	-
Easier driving - fewer turns	1	-	1
Easier driving - safer	2	-	2
Habit - have always used it, used to it, familiarity, know it best, only one I know	5	-	5
Don't know; directed to go that way	2	2	-
Total	107	44	63

veloped from data taken from the Shirley study because it was the only one made by the total-trip method, and it was felt that any rapid mechanical assignment would have to be based on the total trip. These curves are not adapted, therefore, to assigning transfers which are measured between points of choice. For trip lengths measured by points of choice, distance ratios will be lower than the corresponding total trip ratio for values under 1.0 and higher for ratios over 1.0. Speed ratios will be higher by the point-of-choice method, since the part of the trip which is excluded is nearly always via city streets, thus giving more weight to the higher speeds for the expressway portion of the trip in figuring the average overall speed for the expressway trip.

Figure 6 shows the curves which relate distance ratio, speed ratio, and percent of expressway usage. The addition of the speed ratio variable makes it possible to assign different percentages of expressway use for trips having the same distance ratio but different speed ratios.

For transfers having equal distance by the two routes (distance ratio = 1.0) the amount assigned can vary from 7 percent for a speed ratio of 0.8 (which means speed is less via the expressway than city streets) to 100 percent when the speed ratio is 1.9 or above (see Figure 6). The reason for the difference in use can be seen more clearly through the following explanation:

TABLE 6

ADVANTAGES OF EXPRESSWAY DRIVING

Advantage	Total	Route Used on Last Trip to Downtown Detroit: Used Expressway	Used City Streets	No trip Downtown	Frequency of Using Expressway in Last 6 Mo.: Zero-four Times	Five-Twenty Nine times	Thirty or More Times
I save time in getting where I want to go if I use them.	52	20	17	15	11	15	26
I feet less strain, annoyance and frustration in getting where I want to go.	49	17	15	17	11	19	19
I cut down on the distance I have to travel if I use them.	20	2	11	7	4	9	7
The driving surface of expressways is in better condition than other roads I could use.	11	2	5	4	4	4	3
I can go at the speed I wish to travel.	11	-	3	8	8	3	-
I feel safer going by expressways	10	2	2	6	1	6	3
No particular advantage	15	1	9	5	14	1	-
No answer	5	-	1	4	5	-	-
Total	173	44	63	66	58	57	58

of all individual zone-to-zone transfers were within 15 percent of the observed volumes.

In addition to the reliability and the range of trip types which are covered, these curves have an advantage over other two-variable solutions in the ease with which the ratios can be calculated. To calculate distance ratio, all that is needed is the distance via city streets and distance for the expressway route. Then the distance via expressway is divided by the distance via city streets. Speed ratio can be calculated using only measures of distance, if an assumption is made as to the ratio of speed for pure expressway travel to city street travel.

As an illustration, assume that speed on the expressway is twice the speed for city street travel. In the diagram in Figure 7, two routes are shown for a trip from origin to destination. One, Route C, is via city streets and at a speed of 1. The second route, AXB, is via an expressway, with X representing the expressway portion, at a speed of 2, and A and B at a speed of 1, representing the city street travel in getting to and from the expressway.

Speed ratio is calculated as follows:

$$\text{Speed ratio} = \frac{\text{speed via expressway route}}{\text{speed via city street route}}$$

$$= \frac{\dfrac{\text{distance via expressway}}{\text{time via expressway}}}{\dfrac{\text{distance via city streets}}{\text{time via city streets}}}$$

$$= \frac{X + A + B}{\dfrac{\frac{X}{2} + A + B}{\frac{C}{C}}}$$

$$= \frac{X + A + B}{\frac{X}{2} + A + B}$$

$$= \frac{\text{Total Expressway Trip Distance}}{\text{One-half portion on the expressway + distance to and from the expressway}}$$

Therefore, the speed and distance ratios can be calculated from distance measurements with an assumption of ratio of speeds on expressways to speeds on city streets. The assumption of the ratio of speed on expressway to speed on city streets for some future date is just as logical as the assumption of actual speeds and measurements of time for individual streets in the future. These two-variable curves represent a mean percentage of use for the various distance-ratio and speed-ratio groups, just as the distance-ratio curves represented the group behavior of each distance ratio.

As pointed out earlier, there is considerable variation in percentage of expressway use for various distance ratios. Likewise, there is some difference in the percent of trips using an expressway when distance and speed ratios are the same. However, the range of variation is much greater for the single variable distance-ratio curve. The obvious reason for this is that the speed and distance ratio curves give the possibility of many distinctive groupings, thus grouping fewer transfers together, resulting in a smaller range in expressway usage. Distance ratio by itself explains only a portion of the variation in expressway usage. The addition of the speed breakdown within distance ratio helps to explain some of the variation around distance-ratio points.

TABLE 7

DISADVANTAGES OF EXPRESSWAY DRIVING

Advantage	Total	Route Used on Last Trip to Downtown Detroit			Frequency of Using Expressway in Last 6 Mo.		
		Used Expressway	Used City Streets	No trip Downtown	Zero-Four Times	Five-Twenty Nine times	Thirty or More Times
I lose time in getting where I want to go if I use them.	7	-	6	1	3	4	-
I feel more strain, less at ease and more annoyed and frustrated in getting where I want to go.	2	-	-	2	2	-	-
I increase the distance I have to travel.	27	6	11	10	8	9	10
The driving surface of the expressways is in worse condition than other roads I could use.	20	4	7	9	5	6	9
It is difficult to go at the speed I wish to travel on expressways.	2	2	-	-	-	2	-
I do not feel as safe going by expressway	40	9	19	12	16	14	10
Don't know	2	-	-	2	2	-	-
No Particular disadvantage	68	23	19	26	17	22	29
No answer	5	-	1	4	5	-	-
Total	173	44	63	66	58	57	58

The difference in expressway use when distance and speed ratios are the same could be due to several factors; however, the amount each contributes to the variation is not known. Most important from the standpoint of control is the variation in trip length. For

example, a driver making a trip 10 miles long with a distance ratio of 1.0 and speed ratio of 1.5 saves more time using the expressway than a driver making a 5-mile trip with the same distance and speed ratio. Therefore, longer trips will probably divert at slightly higher rates than shorter trips for advantageous ratio combination, even though the distance, speed, and time ratios are the same for both groups of trips. Conversely, when distance- and speed-ratio combinations are disadvantageous for the expressway, the long trips would divert at a slightly lower rate than the short trips. If trip lengths are normally distributed within the distance-speed ratio groupings, then the mean percentage use for the distance-speed ratio group would produce an accurate assignment.

Other factors which cause the variation around the means for distance and speed ratio groups cannot be controlled. For example, some of the variation is due to errors caused by sample variation, grouping of trips at zone centers for measurement purposes, and perceptions and attitudes of drivers.

ANALYSIS OF SUBJECTIVE DATA

The purpose of the second phase of the study was to see what subjective factors correlated with diversion to expressways. In contrast to the previous material, these data were not developed to predict diversion from origin-destination data. However, subjective data could be expected to shed some light on the factors which condition the drivers' choices of routes and make possible more-intelligent use of diversion estimates.

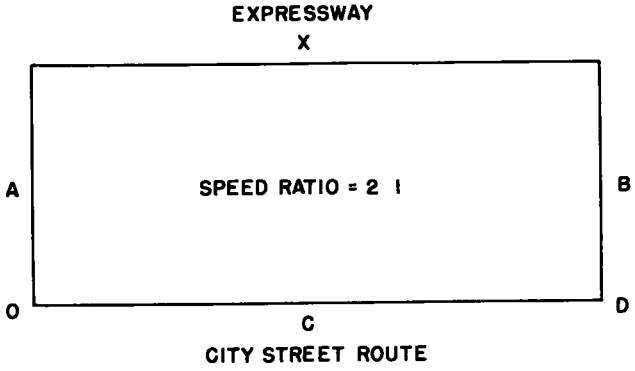

Figure 7. Diagram illustrating a trip between two points O and D via city streets and via an expressway.

Advantage of Route Chosen

One of the primary problems investigated was that of the reasons for choosing one route rather than another. Having evidence from previous studies, it could be expected that both time and distance would come out strongly. But the manner in which this would be expressed was a point of considerable interest. The role played by other factors, especially those which were not objectively measurable, was also a matter of concern.

After naming the route they actually used, drivers were asked to name the advantages they saw in using that route. The results are given in Table 4. Perhaps the most interesting feature of this table is the predominance of distance and time-oriented responses (71 percent of respondents answering the question[9]).

Time savings or other indices based on time can be seen to summarize a wide variety of different motivations for using expressways. The meaning of "quicker" for the driver hinges around two principal dimensions: actual minutes saved and freedom of movement. Although in many cases these go together in the individual's mind, they can vary independently. Safety did not come out strongly in response to this open-ended question.

[9] This figure would undoubtedly be higher if the cases placed in such categories as "less traffic" could be distributed between the categories "quicker, less traffic" and "easier, less traffic."

TABLE 8

PREFERENCE FOR EXPRESSWAY DRIVING AND SATISFACTION WITH EXPRESSWAY EXPERIENCE

	Highly Satisfactory	Fairly Satisfactory	Fairly Unsatisfactory	Highly Unsatisfactory	Never Used Willow Run Expressway	Total
I very much prefer expressway driving	64	27	1	1	-	93
I somewhat prefer expressway driving	15	19	1	-	1	36
I have no particular preference	3	9	1	-	1	14
I somewhat prefer city street driving	4	7	1	-	2	14
I very much prefer city street driving	4	2	4	4	1	15
No answer	-	-	1	-	-	1
Total	90	64	9	5	5	173

TABLE 9

EFFECT OF PREFERENCE AND SATISFACTION UPON USE OF THE EXPRESSWAY, SHOWN BY CONTROLLING THE DISTANCE RATIO

Distance Ratio	Percent Using the Expressway	
	High Preference High Satisfaction	Low Preference Low Satisfaction
.75 - .84	100	-
.85 - .94	100	-
.95 - 1.04	79	67
1.05 - 1.14	33	33
1.15 - 1.24	50	40
1.25 - 1.34	30	15
1.35 - 1.44	25	14
1.45 - 1.54	0	0
1.55 - 1.64	0	-
1.65 or more	0	0

TABLE 10

EFFECT OF PREFERENCE AND SATISFACTION UPON USE OF EXPRESSWAY, SHOWN BY CONTROLLING THE TIME RATIO

Time Ratio	Percent Using the Expressway	
	High Preference High Satisfaction	Low Preference Low Satisfaction
.45 - .54	100	-
.55 - .64	100	100
.65 - .74	100	50
.75 - .84	53	44
.85 - .94	29	25
.95 - 1.04	25	25
1.05 - 1.14	0	0
1.15 - 1.24	0	-
1.25 or more	0	0

Expressway users report time-oriented advantages more than they do distance-oriented advantages, while for nonusers this relationship is reversed. This result, of course, reflects the objective situation. In our sample, most persons who use the expressway gain time and lose distance, while nonusers tend to lose time and save distance by taking city street routes.

The question arises whether people who use the expressway place a higher value on time saving over distance saving than do those who do not use the expressway or whether they are merely in a different objective situation. There is some evidence that the result is not due entirely to the objective situation. Although not shown here, among those who gain both time and distance on the route chosen, expressway users give time-oriented advantages more than nonusers, who typically express the advantage in terms of distance.

A second free-answer question directed at those who did not use the expressway specifically asked why they did not use it. Since this question taps about the same content area, the results also show distance to be the primary consideration for the nonusers; however, the other responses differ somewhat from those given to the previous questions (Table 5). Fear responses came out more strongly (about 13 percent). The responses under "traffic" are actually generated not so much by the expressway itself as the roads which must be used in conjunction with the expressway.

TABLE 11

EFFECT OF THE PERCEPTION OF GAIN OR LOSS OF TIME ON THE PERCENT USING THE EXPRESSWAY

	Percent Using the Expressway	
	Perceive Time Gain	Perceive Time Loss
Objective Gain in Time	68	4
Objective Loss in Time	25[a]	9
Total	65	5

[a] based on only 5 cases.

TABLE 12

EFFECT OF THE PERCEPTION OF GAIN OR LOSS OF DISTANCE ON THE PERCENT USING THE EXPRESSWAY

	Percent Using the Expressway	
	Perceive Distance Gain	Perceive Distance Loss
Objective Gain in Distance	91	100[a]
Objective Loss in Distance	70	19
Total	77	23

[a] based on only 3 cases.

In addition to the free-answer question, two fixed alternative questions were used covering the advantages and disadvantages of expressway driving. The particular advantages and disadvantages given in the questionnaire were chosen on the basis of a pretest. The most-striking difference between Table 6 and those presented previously is the relative importance of the frustration factor, which appears to be of equal importance as time saving. Variations by frequency of use are not significant, although they support the contention that time saving is more important for expressway users independent of their objective situation.

The most-important disadvantage is concerned with safety (Table 7). Of the 98 giving at least one disadvantage, 40 mentioned this factor as being most important. Distance loss is rated as second in importance, while the condition of the driving surface relative to other roads is rated as the third-most-important disadvantage.

Comparing the advantages and disadvantages, 132 out of 168 named three advantages, but only 29 of the 168 gave three disadvantages. When asked to rate the degree of importance of the first advantage and first disadvantage, respondents gave the disadvantages a much-more-minor role than the advantages. It is not surprising, then, that when respondents were asked to say whether the advantages of expressway driving outweigh the disadvantages, or vice versa, 87 percent felt that the advantages are more important than the disadvantages. When broken down by frequency of use, even the low-frequency-user group show 65 percent saying that the advantages outweigh the disadvantages. The middle group in terms of frequency of use showed 95 percent saying the

advantages outweighed the disadvantages, while the high-frequency-user group showed 98 percent saying the advantages outweighed the disadvantages.

Satisfaction and Preference

A high positive feeling for expressways was also revealed in questions dealing with satisfaction and preference (Table 8). When asked to say how well satisfied they were with their experience in driving on the Willow Run Expressway, 90 of the 168 persons who had driven on the expressway reported the experience "highly satisfactory," while 64 persons reported it "fairly satisfactory." Only 14 persons reported it "fairly unsatisfactory" or "highly unsatisfactory."

When asked which they preferred, driving on expressways or driving on city streets, strong preference was reported in favor of expressway driving. Out of the 172 persons answering the question, 93 said they "very much prefer expressway driving" and 36 said they "somewhat prefer" it. Fourteen had no preference, and 14 and 15 respectively "somewhat" or "very much prefer" city street driving. As would be expected, the higher the preference or satisfaction, the greater the use of the expressway.

To see what effect satisfaction and preference have upon diversion, the sample was divided into two groups: a high-preference, high-satisfaction group and a low-preference, low-satisfaction group. The percent diversion was then calculated for the various time and distance ratios. Results are presented in Tables 9 and 10. It will be noted that the high-preference, high-satisfaction group shows a relatively higher percentage of diversion for a given time ratio, or distance ratio, than the low-preference, low-satisfaction group.

Perceived Time and Distance

Drivers could not be expected to have perfect information about the routes they use. To what extent are they aware of losses and gains as a result of taking a particular route? And secondly, what effect do perceptual errors have upon their behavior.

With regard to gains or losses in distance, 73 of 107 drivers (68 percent) were correct when they said they either lost or gained distance. Twenty-eight were incorrect. Expressway users were less accurate in their perceptions of distance than nonusers, tending to say that the expressway distance was shorter than it really was relative to the best city-street route.

The drivers showed about the same degree of accuracy in judging time. Of the 107 drivers, 67 (63 percent) were correct when they said they either lost or gained time. Thirty-five were incorrect. Expressway users were more accurate in their perceptions of time than the nonuser, who tended to overestimate time on the expressway.

Combining the perceptions of time and distance, 41 out of 107 (38 percent) were correct in their perceptions of both time and distance. In addition, 58 (54 percent) were correct on at least one dimension. Only one person was wrong on both, while seven cases were indeterminate.

The significance of these errors in perception is revealed by an analysis of their effect upon behavior. It makes a great deal of difference whether or not the individual is aware that he has a time advantage or disadvantage. For instance, of those who could have gained time by using the expressway and knew it, 68 percent actually used it (Table 11). But among those who could have gained time, but did not know it, only 4 percent used the expressway. Of those who actually would lose time by using the expressway, 25 percent used the expressway when they thought it was quicker, but when they were aware of the loss of time, only 9 percent used the expressway.

Awareness of distance loss shows a similar type of relationship (Table 12). Among those actually losing distance, 70 percent divert when they think they are gaining distance, and only 19 percent who know that they are losing distance use the expressway. Among those actually gaining distance, the percent diverting who are not aware of the gain is somewhat higher than when they know it. The latter result, based on only three cases, is unreliable.

Since driver perceptions do influence behavior, a diversion curve based on the drivers' perceptions might be quite a bit different than one based upon objective data. Probably

it would more closely resemble the all-or-nothing curve than those based upon objective measurements.

Speed and Diversion

One often hears that people drive like maniacs on the expressways. While this type of driving does not seem to be restricted to the expressways, it is possible that persons who drive faster are more inclined to use the expressways. To test this hypothesis, drivers were asked what speed they preferred to drive when traffic conditions on an open highway permitted them to go at any speed. Persons who reported using the expressway 30 or more times in the last 6 months reported speeds which averaged 55.2 mph. Those who used the expressway 5 to 29 times in the last six months named apeeds which averaged 53.3 mph. The low-frequency-user groups, reported speeds averaged 51.8 mph. Similarly, persons who used the expressway on the last trip to downtown reported a slightly higher speed than those who did not use the expressway and those who had no downtown trip. Respective speeds averaged 54.9, 53.7, and 52.1.

On the basis of the above findings, it is probable that faster drivers make fuller use of the expressway. Since they stand to gain a larger amount of time per unit of distance travelled, this is, of course, understandable.

SUMMARY

Many different factors enter into the choice of a route. Some of these are advantages of time and distance freedom of movement, concern for personal safety, comfort in driving. These factors may be considered as forces acting on an individual and tending to move him along one route or another. When all forces are operating in the same direction, the choice of a route presents little problem to the driver. However, forces frequently act in opposite directions so that an individual might, for example have to travel a greater distance to save time, thus making route choice more difficult.

Some of these factors can be measured objectively and related to the behavior of people in mass movements. Other factors are subjective in nature and are difficult to measure. Nevertheless, these subjective factors have an influence on the behavior of people and help to explain some of the variations in their behavior. For example, concern for personal safety may be such a strong force that it will overcome the effect of both time and distance advantage. Drivers' perceptions of time and distance also have an effect on their choice of routes. This study has shown that drivers are not completely accurate in judging which of two routes is longer or shorter in distance or time. Even if they intended to save time, it would require a large difference between the two routes before 100 percent were aware of it.

Thus, the question must be asked whether or not these subjective factors which influence behavior are sufficiently strong that they must be measured and used in predicting expressway usage. Or to put it another way, can objectively measured factors be used to predict diversion, with reasonable assurance that they are accounting for most of the variation in behavior? Since time and distance savings or losses came out strongly as reasons for route choice and since objective measures of time, distance, and speed correlate highly with diversion behavior, it appears that there is no need for including subjective factors in a traffic-assignment formula. The effects of perception, preference, attitude, and other subjective factors apparently cancel one another in group behavior; so their inclusion in an assignment model would not significantly increase the accuracy of assignment.

If subjective factors are not necessary in an assignment formula, which objective factor or factors should be used in assigning traffic to expressways? It is apparent that a curve employing only one variable must be used with extreme caution in an assignment problem. The single variable curves developed from the expressway studies reviewed in this paper are a result of the combinations of speed, distances, times, and trip lengths found in each particular city or on each particular facility. These curves, particularly ones based on time ratio and time differential, varied quite a bit for the different expressways, indicating that the curves have application only in assigning to facilities similar to the facility from which a particular curve was developed. If the facility being

appraised can be classified and the proper curve selected, then a reasonably accurate assignment would be possible using a single variable curve based on time ratio or time differential.

The distance ratio curves did not vary as much for the various expressways as did the ones based on time. Traffic was assigned to the various facilities within ± 5 percent of the total observed volumes by using a curve which was an average of the distance ratio curves for all six expressways. It appears that an average distance-ratio curve would give an assignment within tolerable limits to any single urban expressway having average trip length, time ratio, distance ratio, and speed ratio within the values found for the six expressways studied in this report. However, for single expressways, particularly for an expressway network where longer trips are possible than on one expressway and resulting in higher average speeds, the average distance-ratio curve would not be adequate. The single variable curves, since they classify trip transfers on only one dimension, necessarily group many transfers together, resulting in a wide range of variation around the mean value of expressway usage for individual groupings. This is apparently a normal distribution around the mean, so an assignment based on a single variable gives a close approximation of the total vehicles assigned, even though some individual transfers are assigned high and some low. An accurate assignment of individual zone-to-zone transfers is more important than an accurate total assignment, because ramp and expressway section loads are a result of summing individual zone-to-zone transfer assignments.

The use of a two-variable curve produces a more-accurate assignment of individual zone-to-zone transfers. The reason for this is that two-variable curves based on time, distance, or speed, relate two dimensions of the trip to expressway usage and, through their interrelation, automatically control the third. The addition of a second variable helps to explain some of the variation around the mean occurring in single variable groupings. By establishing more groups with narrower limits, the range of variation around the mean value is reduced.

Two families of curves, each employing two variables, were presented. The first related time and distance differential to expressway usage and the second showed the relation between distance ratio, speed ratio, and expressway usage. The latter is clearly superior, because of the ease with which measurements can be made and the ratios computed and because of adaptability to machine assignment procedures.

CONCLUSIONS

From the data analyzed in this study, the following is concluded:

1. Time and distance savings are the most important considerations in the choice of a rate. Expressway users consider time savings to be more important than distance savings.
2. Drivers' attitudes and perceptions effect their choice of a route, but objective factors account for most of the variation in behavior. In dealing with groups of people there apparently is no need for including the influence of subjective factors in the assignment of traffic to a proposed expressway.
3. An assignment of traffic to an expressway based on time ratios necessitates a classification of the expressway being appraised and selection of an appropriate time-ratio curve. Volumes assigned to an expressway by a time-ratio curve could vary almost 100 percent, depending on which curves were selected.
4. An assignment based on time-differentials would vary even more than assignment by time-ratios. Thus, to assign by time differentials involves an even-more-careful appraisal and curve selection than for time-ratio method. In addition to the difficulty of selecting a curve for either time ratio or time differential, it would be difficult to estimate travel times on expressways and city streets some 20 years in the future.
5. Distance differential has little application as a predictor of expressway usage.
6. Distance ratio appears to be better adapted to universal assignment than any other single variable curve. A curve made from averaging distance-ratio curves from six expressways, assigned to five out of six expressways within ± 5 percent of observed total volume. However, individual zone-to-zone transfers may vary widely in assignment. While distance ratio might work in assigning to an expressway with speed, dis-

tance, and time characteristics similar to expressways used in this study, it obviously would not work for an expressway or expressway network which might accommodate different combinations of trip speeds, distances, and times.

7. Assignment to a single expressway which does or does not have the same characteristics of the ones studied or assignment to a network of expressways which would have a whole variety of combinations of time, distance, and speed suggests the use of a family of curves employing two variables. The two-variable curves are suggested, because they offer many more groupings into which zone-to-zone movements can be classified and also narrow the range of variation around mean values. A family of such curves would facilitate a more-accurate assignment of zone-to-zone transfers.

8. The distance-ratio-and-speed-ratio curves appear to offer a simple, fast, and accurate method of assignment.

These speed-distance-ratio curves were used satisfactorily in assignments to an expressway network in Detroit. Through a mechanical procedure developed by the study staff, an assignment of 25,000 zone-to-zone movements to a network of 260 miles of expressways was completed in less than three weeks. This mechanical assignment procedure is the subject of a paper to be presented at the annual meeting of the Highway Research Board in January of 1956.

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