

# Characteristics of Passenger Car Travel on Toll Roads and Comparable Free Roads

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Among the factors important to an accurate analysis of the benefits accruing to passenger car users through highway improvements are (a) average over-all rates of fuel consumption and speed by type of road, (b) the effects on passenger car operation of traffic impedances, (c) relative attractiveness of the different types of highway improvement benefits to motorists, and (d) the value to motorists of time saving and increased driving comfort. Data useful to passenger car benefit studies in connection with each of these factors were obtained in 1959 during the operation of a passenger car over 14,000 mi on primary highways in 17 States. These data included rates of fuel consumption, over-all speeds, speed changes identified by cause, and records of all traffic impedances.

The study route included, in addition to many miles where the only service was provided by free roads, 14 sections of toll route where drivers traveling between two particular points have a choice between use of a toll route or an alternate free route. At each of these comparison sections vehicle data were collected for trips on both the toll and free routes. In addition, roadside interview stations were operated on each of the alternate routes to determine the percent of local drivers choosing the toll route in preference to the free route and the reasons given by drivers for electing to use whichever route they were interviewed on.

The average over-all rates of fuel consumption and speed on major existing highways and on toll routes are presented in tabular form, with the variation in the over-all rates of fuel consumption and speed as affected by the frequency of driveways and crossroads shown by bar diagrams. The effects of traffic impedances on passenger car operation, the proportion of passenger car users electing to use the toll route at each of the 14 toll route comparison sections, and the relative attractiveness to users of the types of benefit realized on both the toll routes and free routes are given in a series of tables.

Finally, the data collected at the toll route comparison sections were subjected to a separate analysis to obtain estimates of the value to motorists of the time saving and increased driving comfort achieved through highway improvements.

●AN ACCURATE determination of the benefits accruing to passenger car users through highway improvements of various kinds is of paramount importance in high-

way user benefit studies. The number of passenger cars on the roads and streets and the volume of passenger car travel accumulated each year makes the aggregate benefits from highway improvement for this type of vehicle greater than the combined total for all other types of vehicle.

Among the important factors in passenger car benefit studies are (a) fuel and time consumption both on thoroughfares having numerous traffic signals, access points, and sharp curves, and on divided highways with no traffic signals and fully controlled access, (b) the effect of traffic signals, access points, and curvature on highway vehicle operation, (c) the relative importance to motorists of the various types of benefit accruing through highway improvements, and (d) estimates of the value to the motorists of the time saving and increased driving comfort accruing to users through highway improvements. These items are concerned both with the over-all effects of certain types of highway improvement on passenger car operations and with the values drivers place on improved travel conditions. Numerous other factors having important effects on passenger car user benefits, such as the relationship between highway design characteristics and accident rates, the effect of surface conditions and vehicle speeds on vehicle maintenance costs, and the value of reduced travel distance, are not included in this study.

Fuel and time consumption in passenger car operation is affected by several highway factors: (a) length, (b) relation of capacity to average daily traffic, (c) frequency of sharp curves, intersections-at-grade and driveway entrances, (d) surface type, and (e) gradients. Data are currently available on the fuel and time consumption of passenger cars as affected by each of these factors and several studies have been made on the over-all fuel and time consumption of passenger cars operating over limited distances under a particular set of highway conditions (1, 2). However, for benefit studies of large-scale improvement projects more information is needed on over-all average speeds and average fuel consumption rates for operation on typical present day highways and on highways constructed to the highest design standards. Predictions of the time and fuel benefits to arise through a general highway improvement program can be made by summing the savings for each item of improvement such as elimination of intersections-at-grade and addition of traffic lanes. However, time and fuel savings computed in this manner should be compared with the difference in over-all fuel and time consumption of highways of the general type as that involved in a particular analysis, and highways built to high standards, to guard against inadvertently inflating benefits by counting the same items of benefit more than once. Moreover, average over-all values of time and fuel consumption for operation on roads which have intersections-at-grade, access points, and sharp curves, and for operation on divided highways with full control of access can often be used to make preliminary estimates of the fuel and time savings to result from a major highway improvement project.

Traffic impedances such as traffic lights, access points, and sharp curves, affect vehicle operation by forcing drivers to make undesired stops and slowdowns. These speed changes not only increase fuel and time consumption but are annoying to drivers. As an aid to estimating the extent of the benefits to accrue to motorists through highway improvements that eliminate these impedances, information should be available on the frequency of the different types of impedances, the average speed changes caused by each impedance and, in the case of stops for traffic signals and stop signs, the average duration of the stopped delays.

An aspect of user benefit analysis of significance in connection with passenger car benefit studies is the relative preference of users for the various types of benefit arising through highway improvement. Information on the relative attractiveness to motorists of reduced travel cost, time saving, greater safety, and increased driving comfort can be of material assistance in the computation of benefits by providing a guide to the kinds of improvement most desired by users and to the relative advantages, from the users point of view, of the types of benefit realized from these improvements.

A knowledge of motorists' evaluation of two of the benefits brought about by high-

way improvements, time saving and increased driving comfort, is of paramount importance in passenger car benefit studies. Many highway improvements, particularly those on a large scale in rural areas, bring about higher average operating speeds. Because for the normal range of passenger car speeds in rural areas operating costs for fuel, oil and maintenance increase with increased speed, these improvements frequently result in increased operating costs (3). Consequently most of the benefits accruing to passenger car users through highway improvement are those associated with time saving, increased driving comfort, and safety. The benefits to users resulting from reductions in accident rates through road improvements are subject to continuing study and research. The monetary values to users of time saving and increased driving comfort have an importance in benefit analyses at least as great as accident cost saving and warrant thorough investigation.

### FIELD STUDY

The four factors previously discussed were investigated during the summer of 1959 by operating a passenger car a distance of 14,000 mi on primary highways in 17 States and collecting a variety of data relative to passenger car operation and highway travel characteristics. Included as portions of the study route were 14 locations where a major free route and a toll road are in position to serve the same traffic. At each of these locations several comparison runs were made on both the free road and the toll road. At the time of these test runs origin-and-destination interview stations were operated on each route to determine the relative use of the roads and to record trip purpose and driver preference data.

#### Study Vehicle

The vehicle used for the study was a 1959 six-cylinder 4-door standard station wagon of popular make equipped with automatic drive. It was necessary to use the station wagon rather than a sedan or other type of passenger car to provide sufficient interior space to carry the bulky equipment for recording study data described later. Although the vehicle was new and had been operated only 3,380 mi at the beginning of the study, it was placed on a dynamometer and its engine performance given a special check immediately preceding the study. All engine defects discovered at this time, however minor, were corrected. During the 2-month study period while the vehicle covered over 14,000 mi of travel, all recommendations of the manufacturer in regard to vehicle care and maintenance were strictly adhered to.

The vehicle weight and cross-section dimensions were carefully determined. The gross weight of the vehicle, when loaded with the data collecting equipment and carrying both the vehicle operator and the observer, was 4,900 lb. The frontal cross-section of the vehicle itself was 6 ft wide by 5 ft high, the same as for a passenger car of the same make, but the total cross-section was increased by an open-top wooden box affixed to the roof of the vehicle to support and protect a gasoline-powered generator, needed to provide electrical power to operate the data collecting equipment located inside the station wagon. This box added  $1\frac{1}{8}$  ft to the vehicle height for almost the full width of its roof. The full cross-section of the vehicle when equipped for collecting data was 6 ft wide by  $6\frac{1}{2}$  ft high.

#### Equipment for Measuring and Recording Data

The data collecting equipment (described in detail in the following paragraphs) consisted of an electronic device for measuring distance and speed data, an automatic printer for recording distance, speed and time data, a code box for manually adding code numbers to the printer record tape, a fuelmeter, and several hand counters.

The items of electronic equipment were interconnected as a unit called the traffic impedance analyzer (Fig. 1). The instrument for measuring distance and speed was actuated by a flexible cable connection to the cable of the vehicle's speedometer. The output information from this instrument was directed as a series of electrical impulses into the automatic printer through appropriate electrical connections. The printer re-

corded once each second on a strip of paper tape, the travel distance in miles and hundredths of a mile from a fixed point, usually the beginning point of a study run, the vehicle speed in miles per hour (to the nearest mile), and the elapsed time in seconds since leaving the initial point of the study run.

A manual code box with 20 push buttons arranged in two columns of 10 buttons each enabled the observer to record any number from 0 through 9 in each of two columns of the printer tape, changing the numbers each second if necessary. A typical sample of the printer tape is shown in Figure 2. A recent article (4) contains a full description of the traffic impedance analyzer and an explanation of the operation of its component parts.

Vehicle fuel consumption data were obtained using a bellows-type fuelmeter connected to the gasoline line of the vehicle between the fuel pump and the carburetor. The instrument was mounted on the front seat of the vehicle beside the driver so as to be easily read by the observer who sat on the rear seat. The fuelmeter, which gave fuel consumption readings to the nearest  $\frac{1}{60}$ th of a gallon, was read and the data recorded by the observer at each study check point as described in the section on "test procedure." Fuel consumption data as obtained by reading the fuelmeter were continuously checked for accuracy during the study by comparing the difference in fuel readings between successive additions to the fuel tank with the quantity of fuel put into the tank as measured by the gasoline station fuel pumps.

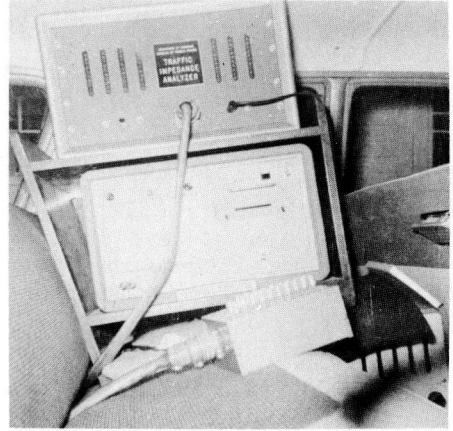


Figure 1. Traffic impedance analyzer.

4	9	7	8	3	2	2	5	9	2	0	
4	9	7	7	3	2	2	5	8	1	3	← Speed in miles per hour
4	9	7	6	2	2	2	5	7	1	8	
4	9	7	5	2	2	2	5	7	1	2	Distance in hundredths of a mile
4	9	7	4	2	5	2	5	7	2	0	
4	9	7	3	2	5	2	5	6	2	2	Manual code
4	9	7	2	2	0	2	5	6	2	5	
4	9	7	1	2	0	2	5	5	2	4	Time in seconds
4	9	7	0	2	3	2	5	5	2	4	
4	9	6	9	2	3	2	5	4	2	1	
4	9	6	8	2	3	2	5	4	2	2	

Figure 2. A typical recording sample from the traffic impedance analyzer.

### Study Route

The study route ran north from Washington, D.C., by way of Elizabeth, N.J., to Syracuse, N.Y. From Syracuse it ran east to Boston, Mass., and thence north to

Portland Me. From Portland the route ran westward through Syracuse, Buffalo, N. Y., Toledo, Ohio, Elkhart, Ind., Springfield, Ill., and Hannibal, Mo., to Wichita, Kans. From Wichita the route ran south through Tulsa and Oklahoma City, Okla., to Ft. Worth, Tex. From Ft. Worth the route ran eastward through New Orleans, La., and along the Gulf coast to Tallahassee, Fla., then southward to West Palm Beach, Fla. From West Palm Beach the route ran northward through Daytona Beach, Fla., Jacksonville, Fla., Savannah, Ga., and Richmond, Va., to Washington, D.C. The termini of each of the sections of the study route, together with route numbers, are given in Table 1 in the order in which the data were obtained except that all toll road comparison sections are given first (Fig. 3).

TABLE 1  
ROUTE NUMBERS AND TERMINAL POINTS OF STUDY SECTIONS USED FOR INVESTIGATION OF  
PASSENGER CAR OPERATING CHARACTERISTICS

Section No.	Initial Point	End Point	Route	Toll Route (toll route comparison sections only)	Remarks
1	Elizabeth, N J	Delaware Memorial Br	US 1 and US 130	New Jersey Tnpk	3 trips each route
18	Trenton, N. J.	Delaware Memorial Br.	US 130	New Jersey Tnpk	3 trips each route
19	Camden, N. J.	Delaware Memorial Br.	US 130	New Jersey Tnpk.	3 trips each route
2	Syracuse, N. Y.	Utica, N. Y.	NY 5	New York Thruway	3 trips each route
3	Syracuse, N. Y.	Harriman, N Y.	US 81, US 11, US 17	New York Thruway	3 trips each route
4	Portsmouth, N. H.	Massachusetts line	US 1	New Hampshire Tnpk.	3 trips each route
51	Portland, Me.	Kittery, Me.	US 1	Maine Tnpk	3 trips each route
6	Toledo, Ohio	Indiana line	US 20	Ohio Tnpk	3 trips each route
7	Elkhart, Ind	Ohio line	US 20	Indiana E - W. Toll Rd.	3 trips each route
8	Wichita, Kan.	Wellington, Kan	US 81	Kansas Tnpk.	3 trips each route
9	Wichita, Kan.	Topeka, Kan.	US 81, US 50, US 75	Kansas Tnpk.	3 trips each route
10	Tulsa, Okla.	Oklahoma City, Okla	US 66	Turner Tnpk.	3 trips each route
20	Tulsa, Okla.	Miami, Okla.	US 66	Will Rogers Tnpk.	3 trips each route
11	West Palm Beach, Fla.	Ft. Pierce, Fla.	US 1	Sunshine State Pkwy.	3 trips each route
30	Braman, Okla.	Tulsa, Okla	US 17, US 77, US 75	-	Free road only
31	North city limit Oklahoma City, Okla	South city limit Oklahoma City, Okla.	US 77	-	Through Oklahoma City
32	Moore, Okla.	Ardmore, Okla	US 77	-	Free road only
33	Ft. Worth, Tex.	Dallas, Tex.	US 80	-	Free road only
34	Ft. Worth, Tex.	Dallas, Tex.	Dallas-Ft. Worth Tnpk	-	Toll road only
35	Center of Dallas, Tex.	E. city limit, Dallas, Tex.	US 80	-	Through Dallas
36	West city limit Shreveport, La.	East city limit Shreveport, La.	US 80 and US 71	-	Through Shreveport
37	Shreveport, La.	Baton Rouge, La.	US 71 and US 190	-	Free road only
38	North city limit Baton Rouge, La.	South city limit Baton Rouge, La.	US 61	-	Through Baton Rouge
39	Gonzalez, La.	New Orleans, La.	US 61	-	Free road only
40	Downtown New Orleans, La.	Residential area New Orleans, La.	US 90	-	Through New Orleans
41	New Orleans, La.	Biloxi, Miss.	US 90	-	Free road only
42	West city limit Biloxi, Miss.	East city limit Biloxi, Miss	US 90	-	Through Biloxi
43	Biloxi, Miss.	Mobile, Ala.	US 90	-	Free road only
44	West city limit Mobile, Ala.	East city limit Mobile, Ala.	US 90	-	Through Mobile
45	Mobile, Ala.	Chipley, Fla	US 90	-	Free road only
46	Ft. Pierce, Fla.	Daytona Beach, Fla	US 1	-	Free road only
47	South city limit Daytona Beach, Fla.	North city limit Daytona Beach, Fla.	US 1	-	Through Daytona Beach
48	South city limit Jacksonville, Fla.	North city limit Jacksonville, Fla.	US 1 and US 17	-	Through Jacksonville
49	Jacksonville, Fla.	Woodbine, Ga.	US 17	-	Free road only
50	Center of Savannah, Ga.	North city limit Savannah, Ga.	US 17	-	Through Savannah
51	Hardeeville, S. C.	Walterboro, S. C.	US 17 and US 17A	-	Free road only
52	Walterboro, S. C.	Summerton, S. C.	US 15	-	Free road only
53	Manning, S. C.	Florence, S. C.	US 301	-	Free road only
54	Rowland, N. C.	St. Paul, N. C.	US 301	-	Free road only
55	South city limit Fayetteville, N. C.	North city limit Fayetteville, N. C	US 301 and US 401	-	Through Fayetteville
56	South city limit Raleigh, N. C.	North city limit Raleigh, N. C.	US 401	-	Through Raleigh
57	Raleigh, N. C.	Norlina, N. C.	US 1	-	Free road only
58	South Hill, Va.	Petersburg, Va.	US 1	-	Free road only
59	South city limit Petersburg, Va.	North city limit Richmond, Va.	US 1	-	Free road only
60	North city limit Richmond, Va.	South city limit Petersburg, Va.	Richmond, Petersburg Tnpk.	-	Toll road only

## Test Procedure

The test vehicle was operated on each section of the route for which data were collected from one end of the section to the other in a manner as closely typical of the passenger cars in the traffic stream as possible. This was done by having the vehicle float with the traffic; that is, operate so as to be passed by about the same number of vehicles as it overtook and passed.

During each test run the traffic impedance analyzer automatically recorded on the printer tape speed, distance, and time data each second. The observer, continuously alert to traffic conditions and highway elements affecting vehicle speed, made use of the manual code box to record on the printer tape opposite each speed change a code number to identify the highway factor or traffic event causing the speed change. The code used is given in Table 2. The left column of code numbers identified highway and traffic factors such as number of lanes or whether a highway is divided or not, whereas

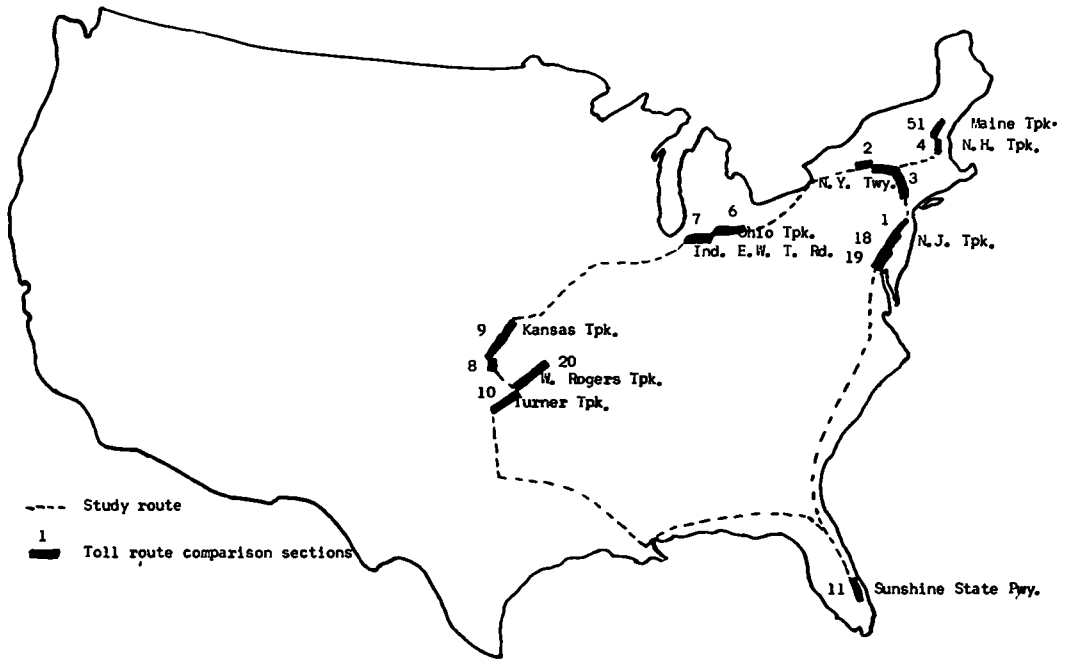


Figure 3. Study route showing 14 road comparison sections.

the code numbers in the right column identified traffic events such as a vehicle suddenly entering from a side road and causing the test vehicle to reduce speed.

The observer manually recorded on a separate data sheet clock time, vehicle odometer readings, fuelmeter readings and fuel temperatures at each of several check points on each test run. The check points were places where the character of the highway changed abruptly. For example, each point where a highway entered or left an urban area, even though it was only a small town, was a check point. Check points were located in this manner to make possible an analysis of the data by type of highway and character of traffic conditions. Check points were recorded on the printer tape using code number 1 in the right hand code column. Because all check points were selected in advance of the test runs, it was a relatively simple matter to go over the printer tape after completion of each run and write on the tape a complete identification of each check point. The clock time and vehicle odometer readings recorded for each

check point constituted a check on the operation of the electronic measuring and recording equipment.

**TABLE 2**  
**TRAFFIC IMPEDANCE ANALYZER CODE USED IN INVESTIGATION**  
**OF PASSENGER CAR OPERATING CHARACTERISTICS, 1959**

Button No.	Code	
	Left Column	Right Column
1.	2- or 3-lane rural free-moving traffic.	Check point.
2.	2-lane rural, trailing another vehicle—unable to pass.	Traffic signal.
3.	4- or more-lane rural without access control.	Stop sign or flashing red signal, if stopped, otherwise trailing truck.
4.	4- or more-lane rural, divided with access control.	Sharp curve or turn if slowed down, railroad crossing if stopped.
5.	2- or 3-lane urban, free-moving traffic.	Residential driveway where entering or leaving vehicle affected test vehicle.
6.	4- or more-lane urban, free-moving traffic.	Commercial driveway where entering or leaving vehicle affected test vehicle.
7.	2- or 3-lane urban congested traffic conditions.	Overtaking and passing maneuver by test vehicle.
8.	4- or more-lane urban congested, traffic conditions.	Effect of school bus in rural areas, or double-parked vehicles in urban areas
9.	2-, 3- or 4-lane urban, one-way, free-moving traffic conditions.	Vehicle turning into highway from crossroad affecting test vehicle.
0.	2-, 3- or 4-lane urban, one-way, congested traffic conditions.	Blank.

The number of access points were recorded for each study section because of their effect on traffic operations and vehicle fuel consumption. A separate count was made for crossroads and cross streets, residential driveways, and commercial driveways. Thus, all points of access to a section of highway over which test data were collected were counted from check point to check point with hand counters and recorded on the data sheet. Each intersecting highway or street was counted as one crossroad regardless of whether it crossed the study route or terminated at it. All residential driveways on both sides of the route on divided as well as undivided highways were included in the total count of residential access points. Similarly, all entrances and exits to commercial establishments on both sides of the route were counted for the

count of commercial access points. Where a commercial entrance was very wide, each 40 ft of width was counted as one access point. The observer counted commercial and residential driveways with two hand counters while the vehicle operator counted crossroads with a third hand counter.

On each of 14 sections of the study route designated as toll route comparison sections, users desiring to travel from one end of the section to the other had a choice between using a major non-toll highway built to standards associated with roads of uncontrolled access and a toll road built to conform with the highest design standards (Table 1). At each of these sections a special study was carried out to obtain directly comparable data of passenger car operations on the toll roads and the alternate free routes. In most cases, the toll road routes included short sections of free route at each end to connect the toll routes to the free routes at the common end points.

At each toll route comparison section three test runs were made on the free road from the designated initial point to the end point. The comparable toll road trips were made as return trips on the toll road for each free road trip. Special runs made on the New York Thruway where the severest terrain conditions were found, demonstrated that there was no significant difference in toll road data by direction of travel. The operation of the vehicle on test runs and the kinds of data collected on each run were the same for all test runs except that on the toll road the electronic recording equipment was operated for only one test run at each comparison section. It was not considered necessary to operate the traffic impedance analyzer to record speed changes for more than one toll road run because of the inherent uniformity of speeds encountered in toll road operations.

### Roadside Interview Stations

Roadside interview stations were operated on both the toll road and the alternate free route at each toll route comparison section to obtain information both on the relative use of the two routes and on the factors affecting user selection of one route in preference to the other. The drivers of all passenger cars operating in the direction from the initial point to end point of each comparison section during a 1-day interview period (8 a. m. to 8 p. m.) were stopped at each interview station and asked the following questions:

1. What is the origin of this trip? (If the origin reported was the city in which the initial point of the comparison section was located, the driver was asked to give the street address.)
2. What is the destination of this trip?
3. What is the purpose of this trip?
4. Why are you using this route rather than the alternate toll/free route?

The two interview stations for each comparison section were operated by the highway department of the State in which the particular section was located during the week that the test runs were being made.

### **ANALYSIS**

Four separate analyses were made: (a) a comparison of average over-all speeds and rates of fuel consumption of a 4,900-lb passenger vehicle for operation on highways with the highest design standard (toll roads) vs operation on major thoroughfares without access control and without many of the other modern design features; (b) determination of the effect of traffic signals, access points, and sharp curves on passenger car operation on major thoroughfares; (c) an analysis of the relative use of toll and free routes; and (d) an investigation of the average motorist's evaluation of the time saving and improved driving comfort resulting from highway improvement.

### Fuel and Time Consumption

The over-all average speed in miles per hour and the average rate of fuel consumption in miles per gallon were determined for the distance between each successive

check point of each section of the study route. These were computed using the elapsed time, fuel consumption, and distance recorded for the movement between the check points. The speeds and rates of fuel consumption computed for all portions of highway having the same general travel characteristics were then grouped together and the average values found for each group. The average speeds and rates of fuel consumption on primary routes in rural areas, urban downtown areas, urban areas outside the downtown area, and in small towns are given in Table 3.

**TABLE 3**  
**AVERAGE OVER-ALL SPEEDS AND RATES OF FUEL CONSUMPTION OF A**  
**STATION WAGON OF 4,900-LB GROSS WEIGHT ON PRIMARY ROUTES**  
**BY TYPE OF ROUTE AND NUMBER OF TRAFFIC LANES**

Type of Route	Average Over-all Speeds		Average Over-all Rate of Fuel Consumption	
	(mph)		(mpg)	
	2 Lanes	4 Lanes	2 Lanes	4 Lanes
Routes with controlled access: Rural divided highways	-	60.1	-	11.1
Routes without controlled access: Rural roads (exclusive of small towns)	49.7	47.8	12.5	12.5
Main urban routes: Downtown areas of large cities	23.0	24.3	12.5	14.3
Outside downtown areas of large cities	24.9	31.1	14.3	14.3
Small towns	29.6	27.2	14.3	14.3

The results presented in Table 3 demonstrate the general over-all effects on vehicle speeds and rates of fuel consumption of improvements which would result only in an increase in the number of traffic lanes from two to four and those which bring about the upgrading of the typical primary highway of uncontrolled access to the level of routes designed to the highest standards (toll road). This table shows that the speeds and rates of fuel consumption on rural routes are about the same for both 2-lane and 4-lane roads but both are higher on toll routes compared to free routes for the typical traffic volumes using the routes. The slightly lower average over-all speed shown for 4-lane rural roads with no control of access as compared to 2-lane rural roads was undoubtedly due to the much higher traffic volumes encountered on the 4-lane roads.

On free routes in urban areas except small towns the average speeds are greater on roads of 4 lanes than on 2-lane roads, but the fuel consumption rates are about the same. In small towns the average over-all speed is higher for 2-lane roads than it is for 4-lane roads. This result is explained by the greater frequency of traffic signal stops on 4-lane routes than on 2-lane routes in small towns (see item 7 of Table 4). These values indicate generally the speeds and rates of fuel consumption on 2- and 4-lane roads but are inconclusive for direct computation of user benefits because they do not differentiate according to traffic volumes. They are useful, however, as over-all checks on time and fuel benefits computed by other means.

The variation in the average over-all speeds and fuel consumption rates of passenger cars as related to the frequency of driveways and nonsignalized intersections (crossroads) on primary 2-lane rural roads is shown by bar diagrams in Figure 4. This figure may be used to estimate the effects on passenger car time and fuel consumption to result through improvements which reduce the frequency of access points on primary 2-lane rural roads for the ranges of average daily traffic volumes typical of such roads.

Figure 4 shows that where there are fewer than two crossroads per mile both the

average over-all speed and the average rate of fuel consumption decrease with an increase in the frequency of driveways from less than 10 to between 10 and 20 driveways per mile but only the average over-all speed continues to decrease when the frequency of driveways is increased to more than 20 per mile. When the number of crossroads per mile exceeds two, average over-all speeds remain about the same for an increase in driveway frequency from less than 10 to between 10 and 20 per mile. The slight increase in speed shown in Figure 4 for this increase in driveway frequency reflects the fact that in mountainous terrain where there are likely to be few farm entrances because of poor farming conditions, road grades adversely affect vehicle speeds, whereas in flat or rolling terrain, where there is usually a greater frequency of farms, road grades are more conducive to higher over-all speeds. However, average over-all speed drops abruptly for a driveway frequency in excess of 20 per mile.

Little change in rate of fuel consumption results when there are more than two crossroads per mile for an increase in driveway frequency from less than 10 driveways per mile to between 10 and 20 driveways per mile but an increase in driveway frequency to more than 20 per mile results in an appreciable reduction in fuel consumption. The reduced fuel consumption associated with the increase in number of access points is due to the decreased speeds brought about by the increased frequency of driveways.

**Traffic Signals, Access Points and Sharp Curves**

Certain of the effects of traffic signals, access points, and sharp curves on passenger car operation and the frequency of occurrence of these impedances were computed using data collected with the traffic impedance analyzer. These are presented in Table 4 differentiated according to whether the impedances were in rural or urban areas. One important effect of a traffic impedance is to cause changes in vehicle speeds. The average number of speed change units given in Table 4 for each of the three impedances, is the average for each impedance of the arithmetic sum of all speed changes associated with the movement of a vehicle past the impedance, each speed change unit being a change in speed of 1 mph. For example, if a vehicle approaching a traffic signal at 50 mph slows to 25 mph, increases speed to 30 mph, and then slows to a stop followed later by an increase in speed back to 50 mph, the total number of speed change units would be (50-25) plus (30-25) plus (30-0) plus (50-0)

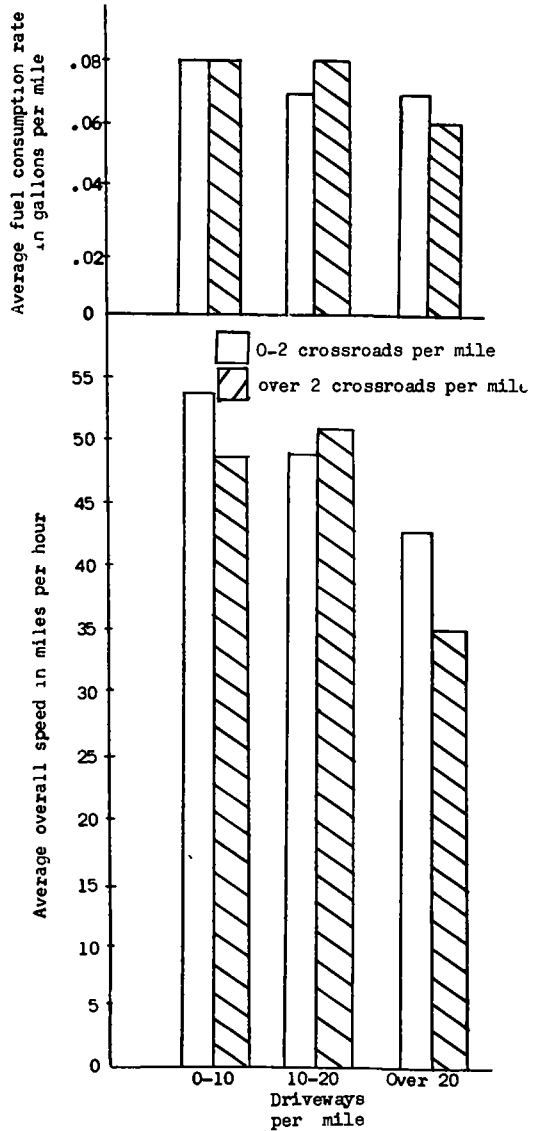


Figure 4. Average over-all speeds and fuel consumption rates on primary 2-lane rural roads as affected by the frequency of driveways and crossroads.

or 110 units of speed change. All single speed changes of 3 mph or less were ignored. The percent of traffic signals at which the study vehicle was stopped and the average duration of traffic signal stops as well as the percent of commercial and residential driveways at which the study vehicle was slowed by vehicles entering or leaving the traffic stream are included in Table 4 as important impedance effects for benefit studies.

**TABLE 4**  
**EFFECT OF TRAFFIC SIGNALS, ACCESS POINTS, AND SHARP CURVES ON**  
**OPERATION OF PASSENGER CARS, AND FREQUENCY OF THESE TRAFFIC**  
**IMPEDANCES ON MAJOR THOROUGHFARES OF THE UNITED STATES**

Item	Urban Area	Rural Area
1. Percent of traffic lights at which study vehicle was stopped	43	30
2. Average stopped delay at traffic signals	0.29 min	0.21 min
3. Average number of speed change units per traffic signal stop <sup>a</sup>	60	90
4. Average percent of driveways (both residential and commercial) at which study vehicle was slowed by entering or leaving vehicles	0.5	0.8
5. Average number of speed change units per access point at which a through vehicle is slowed by an entering or leaving vehicle <sup>a</sup>	20	20
6. Average number of speed change units per sharp curve <sup>a</sup>	15	15
7. Average number of traffic signals per mile	1.96	0.05 (2-lane) 0.20 (4-lane)
8. Average number of residential access points per mile	16.0	5.8
9. Average number of commercial access points per mile	34.2	5.2
10. Average total number of driveways per mile	50.2	11.0
11. Average number of crossroads per mile	10.6	1.9

<sup>a</sup>The number of speed change units for any impedance is the arithmetic sum of speed changes associated with the impedance.

The information presented in Table 4 relative to the effects of driveway access points on vehicle operation is useful for estimating the user benefits to result from the elimination of private driveways. Item 4 shows that the percent of driveways at which the study vehicle was slowed by vehicles entering or leaving the highway at driveways was 0.5 percent (1 in 200) in urban areas and 0.8 percent (1 in 125) in rural areas. Item 10 shows the average number of driveway access points per mile on the free routes studied to be 50.2 in urban areas and 11.0 in rural areas. The average distances traveled by the study vehicle between driveways at which an entering or leaving vehicle caused a slowdown were computed using these values and were found to be 4 mi in urban areas and 11 mi in rural areas.

The values given in items 1 and 2 of Table 4 are useful for predicting the benefits to accrue to highway users through the elimination of a signalized intersection-at-

grade. The average percent of through vehicles stopped by each traffic light on primary roads is 43 percent in urban areas and 30 percent in rural areas with the average stopped delay 0.29 min and 0.21 min in urban and rural areas, respectively. The amount of saving in fuel and time consumption to accrue to users through the elimination of slowdowns due to driveway entrances and stops due to traffic signals can be computed using these data together with data on the fuel and time consumed by highway vehicles for stop-and-go and slowdown operations (1). The usefulness to benefit studies of the speed change data given in Table 4 is described in a later section of this paper in connection with the value to users of improved driving comfort.

### Relative Use of Toll Routes and Alternate Free Routes

The data obtained at the roadside interview stations at both the toll and free routes of each of the 14 toll route comparison sections were analyzed to determine the relative use of high-type roads on which a toll is levied and alternate free routes built to lower design standards. Because the interview data included trip purposes and driver responses to the interview question regarding drivers' reasons for selecting whichever route they were interviewed on, it was possible to extend the analysis to show the relative importance of many of the factors influencing driver choice of route.

In computing the percent of the drivers electing to use the toll road at each comparison section as given in Table 5, only drivers going the full length of the comparison section whose trips originated at the initial point of the particular section were included. Drivers whose trips originated beyond the origin city were excluded because it was felt that these drivers were not local people and not sufficiently aware of the travel characteristics of the comparable routes to make a rational choice. Drivers whose trips originated or ended at intermediate points were excluded because, in most cases, they would have to go an appreciable distance out of their way to make use of the alternate route.

Table 5 also shows for each toll route comparison section the breakdown of the toll road user responses to the interview inquiry as to why they elected to use the toll road instead of the free road. The reasons given by all drivers responding to this inquiry are included, whether or not their trip originated at the initial point of the comparison.

TABLE 5  
RELATIVE USE OF TOLL ROAD AND COMPARABLE FREE ROAD AT TOLL ROAD COMPARISON SECTIONS, AND DRIVER REASONS FOR USE OF TOLL ROAD

Toll Road Comparison Section No	Initial and End Points <sup>a</sup>	No. of Passenger Cars Originating at Initial Point				Percent Using Toll Road	No. of Drivers Responding to Inquiry	Driver Reasons for Using Toll Road <sup>b</sup>									
		Toll Road	Free Road	Total	Percent Using Toll Road			Time Saving		Greater Safety		Less Costly		Greater Comfort and Convenience		All Other Reasons	
								No.	%	No.	%	No.	%	No.	%	No.	%
1	Elizabeth, N. J. to Delaware Mem. Br.	9	5	14	64	94	62	66	3	3	1	1	17	18	11	12	
18	Trenton, N. J. to Delaware Mem. Br.	85	15	80	81	65	54	63	1	2	0	0	6	6	4	6	
19	Camden, N. J. to Delaware Mem. Br.	234	883	1,117	21	321	228	71	15	5	0	0	64	20	14	4	
2	Syracuse, N. Y. to Utica, N. Y.	199	368	567	35	281	237	64	13	5	0	0	12	4	19	7	
3	Syracuse, N. Y. to Harriman, N. Y.	51	28	79	63	84	60	71	3	4	0	0	18	21	3	4	
4	Portsmouth, N. H. to Mass. line	317	159	476	67	3,260	2,665	82	51	1	5	Neg	355	11	104	6	
51	Portland, Me. to Kittery, Me.	241	155	396	60	689	635	78	23	3	0	0	102	15	29	4	
6	Toledo, Ohio to Indiana line	150	142	292	51	4,214	3,416	81	207	5	88	2	0	0	503	12	
7	Elkhart, Ind. to Ohio line	31	9	40	78	184	122	79	8	5	0	0	12	8	12	8	
8	Wichita, Kans. to Wellington, Kans.	210	110	320	66		Data analysis	incomplete				Data analysis	incomplete				
9	Wichita, Kans. to Topeka, Kans.	112	14	126	90		Data analysis	incomplete				Data analysis	incomplete				
10	Tulsa, Okla. to Oklahoma City	512	72	584	68		Data analysis	incomplete				Data analysis	incomplete				
20	Tulsa, Okla. to Miami, Okla.	144	31	175	62		Data analysis	incomplete				Data analysis	incomplete				
11	W. Palm Beach, Fla. to Ft. Pierce, Fla.	63	185	248	25												
All		3,338	2,178	4,514	63	8,228	747	586	333	4	84	1	304	7	782	18	

<sup>a</sup>See Table 1 for other data on toll road comparison sections  
<sup>b</sup>Includes all passenger cars on toll roads regardless of trip origin

The breakdown of avowed reasons for using toll roads given in Table 5 for the 14 toll route comparison sections shows that between 71 and 84 percent of the toll road users elect to use the toll route rather than the free route to save time, 1 to 7 percent for reasons of safety, less than 1 percent to save money, up to 21 percent for improved driving comfort, and up to 12 percent for other reasons. Time saving is the most important single factor inducing drivers to travel on toll roads, with improved driving comfort second in importance. Less than 7 percent of those electing to use the toll road did so for safety reasons. These data indicate that from the passenger car users' point of view the highway improvements which bring about the greatest benefits are those which reduce time consumption and improve driving comfort.

Table 6 shows for the toll routes and free routes of all toll road comparison sections the breakdown of users according to the reasons given by the drivers for electing to use the route they were interviewed on for each of five categories of trip purposes: work, shop, vacation, recreation or social other than vacation, and all others. These values are given both in absolute numbers and as percentages of the total sample in each trip purpose category. All passenger car users moving in one direction on both the toll and free routes during a 12-hr interview period on each of the 10 toll road comparison sections for which data analyses are complete are represented in Table 6. Data analysis is incomplete for toll road comparison sections 8, 9, 10 and 20 (Table 5).

Two items of information of significance in passenger car user benefit studies are brought out in Table 6: the relative importance of the factors inducing passenger car users to elect to use a free road when a toll route is available, and the effect of trip purpose on the relative importance to passenger car users of the factors inducing them to use either toll routes or free routes. The relative importance of the factors inducing passenger car users to use a toll road when a free road is available was given in Table 5 and discussed in connection with that table.

An average of 21 percent of free road users indicated that they decided to travel on the free road to save time, 13 percent to save money, 19 percent for greater driving comfort, and 47 percent for other reasons. A negligible number of free road users thought travel by the free route was safer. The most common reasons given by free road users for using the free route are those included in the category of all other reasons and include less driving monotony, desire to shop or visit at points on the free route, see a particular view, and mechanical difficulty with the vehicle. The percentage of passenger car users who used the free road to save time and the percentage who used the free road to enjoy greater driving comfort are about equal in magnitude and second in importance only to the aggregate of reasons included in the category of all other reasons. Only a small percentage of free road users were influenced to use the free road to save money. It appears that on the free roads as on

TABLE 6  
DISTRIBUTION BY TRIP PURPOSE OF DRIVER REASONS FOR USING EITHER THE TOLL ROUTE  
OR A COMPARABLE FREE ROUTE AT LOCATIONS WHERE A CHOICE EXISTS

Trip Purpose	Type of Route	Driver Reason for Using Selected Route										Total <sup>a</sup>	
		Time Saving		Greater Safety		Less Costly		Comfort and Conven		All Other Reasons			
		No.	%	No.	%	No.	%	No.	%	No.	%		
Work	Toll	2,018	83	72	3	57	2	120	5	173	7	2,440	100
	Free	740	75	0	0	485	16	589	20	1,181	39	2,995	100
Shop	Toll	98	83	5	4	1	1	7	6	7	6	118	100
	Free	181	31	0	0	51	9	137	23	221	37	590	100
Vacation	Toll	3,876	81	185	4	24	Neg	282	6	417	9	4,784	100
	Free	330	12	2	Neg	282	10	441	15	1,809	63	2,864	100
Other social or recreation	Toll	997	78	45	3	7	Neg.	137	11	100	8	1,286	100
	Free	363	24	1	Neg.	161	11	364	24	608	41	1,497	100
Other	Toll	486	73	26	4	5	1	58	9	85	13	660	100
	Free	203	32	0	0	88	14	119	19	217	35	627	100
Total	Toll	7,475	80	333	4	94	1	604	7	782	8	9,288	100
	Free	1,817	21	3	Neg	1,067	13	1,650	19	4,036	47	8,573	100
Grand total	Both	9,292	52	336	2	1,161	6	2,254	13	4,818	27	17,861	100

<sup>a</sup>Includes all passenger car users moving in one direction during a 12-hr interview period at each of the 10 toll road comparison sections for which data analysis is complete (Table 5)

toll roads, when only factors associated with the highway itself are considered, time saving and improved driving comfort are of greatest importance to the passenger car user. The percentage of passenger car users on the free routes that use the free route for reasons of greater comfort and convenience is appreciably higher than the percentage of toll road users that use the toll route for this reason. The explanation for this is probably the greater frequency and wider choice of restaurants, motels, and gaso-line service stations on the free routes.

The effect of trip purpose on the relative importance to passenger car users of the factors causing them to select either the toll route or the free route is also given in Table 6. For the toll road users the relative importance of the various reasons for using the toll road is about the same regardless of trip purpose except that the toll road users traveling to or from work or on shopping excursions are influenced more by time saving and less than by comfort and convenience than are other users. For free road users the relative importance of the reasons for using the free route are nearly the same for all trip purposes except that most users on vacation use the free road for reasons other than time saving, safety, cost outlay, or driving comfort. Only a relatively small percentage of free road users on vacation use the free road either to save time or for greater driving comfort. In general these data indicate that there is no appreciable over-all difference in the importance to users of the various types of benefit by trip purpose.

#### Motorist's Evaluation of Time Saving and Increased Driving Comfort

The data collected at the roadside interview stations by the several State highway departments and by operation of the test vehicle on the toll roads and alternate free routes at the toll route comparison sections were analyzed at the Office of Research of the Bureau of Public Roads to obtain estimates of the value to motorists of the time saving and the greater driving comfort experienced when operating on the toll road. Drivers do not, in general, consciously assign a separate value to each of these benefits. However, because both are effective in influencing driver selection of route, each has a certain amount of attractiveness to users which may be measured in monetary terms.

The analysis was based on the theory that through travelers using toll roads, where a free alternate route is available, pay a premium to do so because they expect to benefit by an amount at least equal to the toll charge. The benefits received would be one or more of the following types of benefit: reduced operating costs, time saving, increased driving comfort and reduced accident costs. The value of two of these benefits can be estimated: operating cost saving, on the basis of the fuel consumption difference on the two routes, and accident cost savings, on the basis of published accident rate and accident cost reports. The problem is to arrive at a value of the two benefits, time saving and increased driver comfort, on the basis of estimated values of the other two benefits, and a known toll charge presumably paid to obtain these benefits.

A difficulty which complicated the problem of evaluating time saving and driver comfort benefits was selection of a suitable unit with which to measure driving comfort. A minute of time could be used to measure time saving but there was no similar unit for measuring improvement of driving comfort. However, it is generally recognized that uniformity of driving speed is a characteristic of good driving conditions. Most of the highway factors that cause driver annoyance, such as traffic lights and sharp curves, cause vehicles to change speed, frequently causing them to reduce speed to a full stop. These considerations lead to the selection of the speed change unit of 1 mph, previously described in connection with Table 3, as the unit of driving discomfort. Each speed change unit eliminated through highway improvement is therefore a unit of driving comfort improvement. In determining the number of units of speed change for a highway, only variations in speed where the speed change is more than 3 mph are included because variations of 3 mph plus or minus are typical of normal driving under the best conditions. Using speed change units as a measure of driving discomfort, the driving discomfort of a section of highway is the arithmetic sum of all speed changes

on that section of road, neglecting all single speed changes of 3 mph or less. The unit value of improved driving comfort is taken in this analysis to be the value to users of each speed change unit of 1 mph saved through highway improvement.

The data obtained at each of the 14 toll route comparison sections are summarized in a convenient form in Tables 7 and 8 for the analysis of the motorist's evaluation of time saving and increased driving comfort. In both tables each toll route comparison section is identified by number and by the initial and end points. Inasmuch as at each comparison section a series of trips were made on both the free route and toll route, all trip data are given in Tables 7 and 8 as differences between the values for a free route trip and a toll route trip. For this purpose each free route trip was paired with

TABLE 7  
TRIP LENGTHS AND RELATIVE USE OF TOLL AND FREE ROUTES, AND SAVINGS IN TIME CONSUMPTION AND SPEED CHANGE UNITS FOR OPERATION ON TOLL ROUTES FOR 14 TOLL ROUTE COMPARISON SECTIONS

Toll Route Comparison Section No	Initial and End Points <sup>a</sup>	No of Traffic Lanes of Free Route	Trip Length		Percentage of Drivers Electing to Use Toll Road <sup>b</sup> (P)	Saving in Time Consumption and Number of Speed Change Units for Toll Route Trips Compared to Free Route Trips by Comparison Trip Pairs <sup>c</sup>		
			Toll Route Miles	Alternate Free Route Miles		Comparison Trip Pairs	Time Saving Minutes ( $\Delta T$ )	Saving in Speed Change Units <sup>d</sup> ( $\Delta D$ )
1	Elizabeth, N. J to Delaware Memorial Br.	4	103.8	107.2	64	A	61	3,410
						B	47	3,430
						C	69	4,290
18	Trenton N. J. to Delaware Memorial Br.	4	55.8	58.7	81	A	34	1,795
						B	30	2,140
						C	28	2,055
19	Camden, N. J. to Delaware Memorial Br.	4	29.2	29.4	21	A	13	595
						B	7	355
						C	5	420
2	Syracuse, N. Y. to Utica, N. Y.	2	53.5	50.4	35	A	15	945
						B	16	1,540
						C	28	2,020
3	Syracuse, N. Y. to Harriman, N. Y.	2	240.1	216.7	65	A	62	4,580
						B	60	4,970
4	Portsmouth, N. H. to Mass. line	2	16.0	16.1	67	A	4	110
						B	7	420
						C	5	145
51	Portland, Me. to Kittery, Me.	2	49.8	48.3	60	A	26	1,915
						B	22	1,190
						C	31	1,280
6	Toledo, Ohio to Ind. line	2	68.9	67.8	51	A	11	410
						B	9	310
7	Elkhart, Ind to Ohio line	2	69.3	62.9	78	A	0	975
						B	2	865
						C	3	745
8	Wichita, Kans to Well, Kans	2	27.2	26.2	66	A	5	50
						B	5	35
						C	4	50
9	Wichita, Kans. to Topeka, Kans.	2	134.8	165.6	90	A	53	1,390
						B	51	945
10	Tulsa, Okla. to Oklahoma City, Okla.	2	86.2	98.6	88	A	38	2,040
						B	35	1,960
						C	39	2,475
20	Tulsa, Okla. to Miami, Okla	2	74.3	80.3	82	A	19	915
						B	16	705
						C	23	830
11	West Palm Beach, Fla. to Ft. Pierce, Fla.	4	65.0	57.4	25	A	2	425
						B	0	475

<sup>a</sup>See Table 1 for other data on toll route comparison sections.

<sup>b</sup>Based on drivers whose trips originated at initial point of comparison section.

<sup>c</sup>A comparison trip pairs consists of one toll route trip and one free route trip.

<sup>d</sup>Time saving and saving in speed change units are for full trip length.

<sup>e</sup>A speed change unit is 1 mph change, plus or minus, for all speed changes in excess of 3 mph.

a toll route trip and the value of the differences in time consumption, speed change units and fuel cost as well as total cost differences are given for these comparison trip pairs. At each comparison section there are at least two comparison trip pairs and at many sections there are three. These are identified by the letters A, B and C.

Table 7 presents data on the number of traffic lanes on the free routes, the trip lengths, both of the toll and free routes, the percentage of drivers electing to use the toll route, and the differences in time consumption and number of speed change units for the two trips of each comparison trip pair. The percentage of drivers electing to travel by toll route was determined using only the drivers on the compared routes whose trip origins were at the initial points of the compared sections.  $\Delta T$  and  $\Delta D$  are the savings in time and speed change units, respectively, for a toll route trip compared to a free route trip.

The cost differences for operating over the routes of each comparison section are given in Table 8 for each comparison trip pair. These cost differences are the toll charge for toll road operation, R, the reduction in accident cost expectancy for operation on the toll route,  $\Delta A$ , and the additional fuel cost for operation on the toll route,  $\Delta F$ . The total additional cost for operation on the toll route as compared to operation on the free route for each comparison pair,  $\Delta M$ , found by use of the formula  $\Delta M = R + \Delta F - \Delta A$  is also given in Table 8.

TABLE 8  
COST DIFFERENCES FOR OPERATION ON TOLL ROUTE AS COMPARED TO OPERATION ON ALTERNATE FREE ROUTE FOR 14 TOLL ROUTE COMPARISON SECTIONS

Toll Route Comparison Section No	Initial and End Points <sup>a</sup>	Toll Charge, R (cents)	Reduction in Accident Cost Expectancy on Toll Route <sup>b</sup> , $\Delta A$ (cents)	Comparison Trip Pairs <sup>c</sup>	Additional Fuel Cost for Operation on Toll Route <sup>c</sup> , $\Delta F$ (cents)	Total Additional Cost for Operation on Toll Route <sup>d</sup> , $\Delta M$ (cents)
1	Elizabeth, N. J. to Del. Mem Br.	130	11 0	A	-1.5	117.5
				B	6.9	125.9
				C	0.9	119.9
18	Trenton, N. J. to Del. Mem Br	60	6.1	A	-6.9	47.0
				B	1.2	55.1
				C	1.5	55.4
19	Camden, N J. to Del. Mem. Br	30	3.0	A	-2.7	24.3
				B	1.8	28.8
				C	2.7	29.7
2	Syracuse, N. Y. to Utica, N. Y.	75	4.8	A	11.7	81.9
				B	8.4	78.6
				C	15.3	85.5
3	Syracuse, N. Y to Harriman, N. Y	370	19.5	A	105.3	455.8
				B	99.0	449.5
4	Portsmouth, N. H. to Massachusetts line	20	1.6	A	1.8	20.2
				B	5.1	23.5
				C	2.4	20.8
51	Portland, Me. to Kittery, Me.	100	4.7	A	21.6	116.9
				B	16.5	111.8
				C	18.0	113.3
6	Toledo, Ohio to Indiana line	90	6.7	A	3.6	86.9
				B	12.6	95.9
7	Elkhart, Ind. to Ohio line	85	5.7	A	36.4	117.7
				B	33.0	112.3
				C	45.0	124.3
8	Wichita, Kans. to Wellington, Kansas	30	2.5	A	14.7	42.2
				B	12.9	40.4
				C	6.0	33.5
9	Wichita, Kans to Topeka, Kans.	245	19.0	A	50.1	276.1
				B	30.6	256.6
10	Tulsa, Okla. to Okla. City., Okla.	140	10.8	A	-7.5	121.7
				B	-12.3	116.9
				C	-1.5	127.7
20	Tulsa, Okla Miami, Okla. West Palm Beach, Fla , to Ft Pierce, Fla	120	8.4	A	24.6	136.2
				B	19.8	131.4
				C	23.4	135.0
11	Fla , to Ft Pierce, Fla	100	5.1	A	52.5	147.4
				B	52.2	147.1

<sup>a</sup>See Table 1 for other data on toll route comparison sections.

<sup>b</sup>Based on unit accident cost expectancy as follows: \$0.07 per vehicle-mi on toll routes and \$0.17 per vehicle-mi on routes without access control.

<sup>c</sup>A comparison trip pair consists of one toll route and one free trip.

<sup>d</sup> $\Delta M = R + \Delta F - \Delta A$

The saving in accident cost expectancy for operation on the toll route given in Table 8 is the difference in the average cost of accidents for a passenger car traversing the full length of each comparison section over the toll route as compared to operation over the free route. The accident expectancy cost of a passenger car on each route is the product of the route length in miles given in Table 7, the average accident rate of all types of accidents per vehicle-mile, and the average cost of a passenger car accident. The average accident rates used in these computations were 151 accidents per 100,000,000 vehicle-miles on toll roads and 332 accidents per 100,000,000 vehicle-miles on roads with no access control as presented in House Document No. 93 of the 86th Congress, First Session (5). The average cost of a passenger car accident on primary rural routes with no control of access is \$521 per accident as determined from a study of accident costs in Massachusetts in 1953 (6). Unpublished data from the Massachusetts Accident Study show that the average cost of a passenger car accident (all accidents) on both primary and secondary rural highways is \$402 per accident. If the types of accidents that very seldom occur on toll roads (head-on collision, head-on side-swipe collision, and collisions with bicycles and scooters) are eliminated, the average cost of a passenger car accident on rural routes is \$369. Assuming that the saving in average passenger accident cost achieved through the elimination of these accident types, \$33 (\$402-\$369), is the same on primary routes as on primary and secondary routes together, the average cost of an accident on toll routes is \$488 (\$521-\$33).

The motorists at the initial points of each comparison section who wish to travel the full distance from the initial point to the end point of a comparison section are faced with the choice between two alternatives: (a) to use the toll road and pay the extra cost,  $\Delta M$ , but save an amount of time,  $\Delta T$ , and a number of speed change units (driving comfort),  $\Delta D$ ; or (b) to use the free road and put up with the additional time consumption and speed changes but saving total cost difference,  $\Delta M$ . The percentage of drivers who elect to use the toll road at each location is  $P$ , given in Table 7.

The first step in the analysis of the data of Tables 7 and 8 to obtain an estimate of the value the average motorist places on the saving of 1 min of trip time,  $t$ , and the value the average motorist places on the saving of one unit of speed change,  $s$ , was establishment of a relationship between these unknowns and the study data,  $\Delta M$ ,  $\Delta T$ ,  $\Delta D$  and  $r$ , where  $r$  equals  $P/(100-P)$ . Equations defining a model of the relationship between these variables have been presented by Cherniack (7). The following simple equation is an adaptation of Cherniack's work appropriate to this analysis as developed by G. P. St. Clair, Director of the Bureau of Public Roads' Highway Cost Allocation Study:  $+\Delta M = -u \log r - t(\Delta T) - S(\Delta D)$ . St. Clair's derivation of this equation is presented in the Appendix.

The values of  $t$  and  $s$  were arrived at by substituting the values of  $\Delta M$ ,  $\Delta T$ , and  $\Delta D$  and  $r$ , where  $r = P/(100-P)$ , from Tables 7 and 8 in a series of equations of the foregoing form and solving by multiple regression. Only data for runs at study locations where the free routes are 2-lane roads were included in the equations. It was considered best not to include data for both 2- and 4-lane free roads in the equation for one multiple regression solution because of the differences in travel characteristics on the two types of road. Of particular concern was the fact that passing maneuvers measured by the amount of speed change represent a greater annoyance to drivers on 2-lane roads than they do on 4-lane roads. The data used in the multiple regression solution are those determined for the 27 comparison trip pairs of the 10 comparison sections where the free routes are 2-lane roads (Table 7).

The computations of the values of  $t$  and  $s$  by multiple regression analysis were made by Nathan Lieder, statistician for the Office of Research of the Bureau of Public Roads. The values of  $t$  and  $s$  together with the confidence limits on the 95 percent level of accuracy were found to be the following:

$$t = 2.365 \text{ cents per minute plus or minus } 0.59 \text{ cent.}$$

$$s = 0.048 \text{ cent per speed change unit plus or minus } 0.062 \text{ cent.}$$

The estimate of the motorist's evaluation of a minute of time saved rounded to the

hundredth of a cent is 2.37 cents on the basis of the data collected for this study. This estimate of the value of time agrees fairly well with the estimate recommended by the American Association of State Highway Officials, 2.58 cents per minute (3).

The estimate of the value to motorists of the elimination of one speed change unit (a 1-mph change in speed) rounded to the hundredth of a cent is 0.05 cent. The variance of this estimate, plus or minus 0.06 cent, is very high, however, and appears to indicate that driver discomfort is not fully measured by speed change units. Certain anomalies in the data and general observations of the field crew of this study also indicate that driver discomfort is greater than shown by number of speed change units. For example, one obviously annoying traffic condition is for a motorist to have to trail a slow-moving vehicle for many miles on a 2-lane road before finding an opportunity to pass. The trailing driver, forced to travel at a slow but uniform speed, is annoyed because his speed is controlled by another driver and because he knows that to gain relief he must pass on a 2-lane road, which in itself is annoying. However, this distress is not reflected in speed change units. It is probable that to arrive at a better estimate of the value to drivers of the elimination of driving discomfort as measured by speed change units, some adjustment must be made to account for annoyances that are not reflected in speed changes.

It is evident, therefore, that further investigation is needed both to obtain more data on speed changes on toll route comparison sections and to incorporate into the analysis of the value to motorists of relief from driving annoyance, other measures of annoyance in addition to speed change units. In connection with the latter, further analysis is planned to exploit field data on the trailing operations of the study vehicle on 2-lane roads which were collected for this study but not contained in this report.

The analysis gives an accurate distribution between the items of time saving and reduced driving annoyances of the average passenger car user's evaluation of the sum of these two benefits. The value to passenger car users of a minute of time saving (2.37 cents) is also accurate because the average number of units of time saving (minutes) can be directly measured. The relatively high value arrived at for each unit of speed change saving (0.048 cent) is due to the allocation of the travel discomfort benefit value among only the number of speed change units saved when it probably should be allocated among the number of speed change units saved plus an unknown number of other discomfort units saved. To the extent that the amount of driving discomfort not measured by number of speed change units is in any way related to the number of speed change units, the product of 0.048 cent and the number of speed change units saved through highway improvement is a reasonable estimate of the value of the improved driving comfort benefit arising through the improvement. This estimate of the user's evaluation of each 1-mph speed reduction may be used to approximate driving comfort benefits arising through improvements which reduce the number of speed change units on roads similar to those for which study data were obtained, primary rural roads without control of access.

In Table 4 the average number of speed change units associated with three impedances, a traffic signal stop, an access point where a through vehicle is slowed by an entering or leaving vehicle, and a sharp curve, are given for operation in rural areas. Multiplying these values by the estimate of the average motorist's evaluation of the elimination of one speed change unit, 0.048 cent, gives the following estimates of the comfort and convenience benefit users receive through the given highway improvements: elimination of a traffic signal stop in rural areas, 4.32 cents; elimination of a sharp curve, 0.72 cent; and elimination of a slowdown to a through vehicle at an access point, 0.96 cent.

#### SUMMARY

Several types of data useful in analyses of the benefits accruing to passenger car users through highway improvement were developed in this study. Among these were average over-all rates of fuel consumption and speed for operation on existing major routes of 2 lanes and 4 lanes in both urban and rural areas and for operation on toll roads. These data showed that there is little difference between over-all speeds on

2- and 4-lane roads except on main urban routes of large cities outside of the downtown areas where over-all speeds on the 4-lane routes were approximately 25 percent greater than on the 2-lane routes. The greatest difference in average over-all operating speed observed was between that for operation on rural 4-lane divided controlled-access routes, 60.1 mph, and that for operation on 2- or 4-lane rural routes without control of access, between 47 and 50 mph. The fuel consumption rate on the rural 4-lane divided, controlled-access routes is about 12 percent greater than on the rural routes without control of access which, in turn, is about 15 percent greater than on urban routes. These differences in fuel consumption rates reflect the overriding effect of speed on rate of fuel consumption. For the typical traffic volumes carried by existing thoroughfares having no access control, there is little difference either in speeds or in fuel consumption rates for operation on 4-lane routes as compared to operation on 2-lane routes.

Certain of the effects of traffic signals, access points (driveways and crossroads without signal protection), and sharp curves on passenger car operation, together with the average frequencies of these impedances on major routes of the United States, are included in this report. The average passenger car driver is required to stop at 43 percent of the traffic lights in urban areas and at 30 percent of the traffic lights in rural areas and, when stopped at traffic lights, suffers an average stopped delay of 0.29 min in urban areas and 0.21 min in rural areas. Also the average driver is slowed by vehicles entering or leaving driveways at 0.5 percent of the driveways in urban areas and at 0.8 percent of the driveways in rural areas. These data, together with data on speed changes and on the average frequencies of impedances, can be very useful in user benefit computations by providing a means of estimating the effects on traffic operations of highway improvements which eliminate individual impedances or groups of impedances.

The relative use of toll routes and alternate free routes by drivers familiar with both routes, and the reasons given by drivers on the compared routes for using either the toll route or the free route are given to show the relative attractiveness to passenger car users of the different types of benefits arising from highway improvements. The type of benefit most important to motorists was found to be time saving with an average of 80 percent of the passenger car drivers on toll roads and 21 percent of the passenger car drivers on free roads stating they selected their travel route on the basis of time saving. The second most important reason given by passenger car users for selecting their route was greater comfort and convenience or less driving strain. The highway benefits of least importance in governing passenger car user's selection of route were found to be greater safety and lower travel costs. Only 13 percent of the free road users indicated that they were influenced not to use the toll road because of the cost factor.

The toll road, free road comparison data were analyzed to arrive at an estimate of the average passenger car user's evaluation of time saving of 2.37 cents per minute of travel time saved and an estimate of his evaluation of an improvement in driving conditions (measured in units of speed change reduction) of 0.048 cents per 1-mph reduction in speed change. The estimate of the value of time saving is of a higher order of accuracy than that for the value of a speed change reduction largely because there are factors affecting driving comfort which are not reflected in speed changes. Because driving comfort was measured only by speed change reduction, the value of each unit of speed change reduction is somewhat high for general use. However it may be used to estimate driving comfort benefits arising through improvements which reduce the number of speed change units on roads similar to those for which study data were obtained, primary rural roads without controlled access.

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### *Appendix*

The following is a derivation of a simple equation relating time saving, saving in speed change units, and cost difference for operation on a toll road rather than a free road, and the percent of traffic using the toll road to user evaluations of a minute of time saving and a 1-mph reduction in amount of speed change.

Assume that the number of daily round trips that will be made from a given origin, O, to a given destination, D, for a given purpose can be represented by the following equation:

$$V_{OD} = [q] [V_O] [I_{Da}] [F(C)] \quad (1)$$

in which

- q = a coefficient related to the propensity to make trips. This value is immaterial for present purposes.
- $V_O$  = number of vehicles domiciled in zone of origin.
- $I_{Da}$  = coefficient of attractiveness of the destination zone, D, for trips of the given purpose, a. Then if the purpose is home-to-work, this coefficient would be related to the number of employed persons in zone D.
- F(C) = a function of the average cost of trip, C.

The number of trips for all purposes is given by the equation:

$$V_{OD} = [q] [V_O] [F(C)] [\Sigma I_n]$$

in which

$\Sigma I_n = I_a + I_b + I_c + \dots + I_n$ , the sum of all trip purpose coefficients.

Let the following represent the cost function:

$$F(C) = 10^{-hC} \quad (2)$$

in which

h is a coefficient to account for the unknown effect of travel cost on driver trip decisions.

This equation can be simplified by putting  $h = 1$ , but this presumably would reduce its generality and force it to conform to a curve that the data might not fit. Furthermore,  $h = 1$  lacks generality, because if base e had been used, it would produce a different function.

In general this function behaves more or less as would be wished. If C is limited to positive values, as it should be, the function has its greatest value, one, when C =

0; and thus the number of trips varies inversely with the cost. It is not a perfect function but it has the virtue of simplicity.

The equation, therefore, takes the form:

$$V_{OD} = [q] [V_O] [\Sigma I_n] [10^{-hC}] \quad (3)$$

Alternative routes: Eq. 3 may be taken as applicable to all trips made from O to D, the cost, C, being taken as the average cost of the trip, OD. There is, however, the problem of the distribution of the trips,  $V_{OD}$ , among two or more alternative routes having different trip costs. The equation will presumably hold for any one alternative, in relation to numbers of trips to other destinations. To assume that it holds for the distribution of trips to the same destination among alternative routes, it is necessary to say that the distribution of motorists subjective appraisals of certain cost elements (values of time and driving comfort) is such that the distribution of trips among alternative routes between the same termini obeys the same cost function.

If the subscript OD is reduced to O or D, according to the point of origin, and the subscripts 1 and 2 are used for two alternative routes between O and D, for trips from O to D the following may be written:

$$\begin{aligned} V_{O1} &= (q) (V_O) (\Sigma I_D) 10^{-hC_1} \\ V_{O2} &= (q) (V_O) (\Sigma I_D) 10^{-hC_2} \\ r_O &= \frac{V_{O1}}{V_{O2}} \frac{10^{-hC_1}}{10^{-hC_2}} = 10^{-h(C_1 - C_2)} \end{aligned}$$

It becomes at once obvious that the result would be exactly the same for the trips originating at D:

$$\begin{aligned} r &= r_O = r_D = 10^{-h(C_1 - C_2)} \\ \log r &= -h(C_1 - C_2) \\ \log r &= -h(\Delta C) \\ \log r &= -h(\Delta M + t \Delta T + s \Delta D) \end{aligned}$$

in which

$\Delta M$  = the net sum of measured cost differences: operating cost, accident cost, expectancy and toll charge,

$\Delta T$  = time difference,

t = unit value of a minute of time saved,

$\Delta D$  = difference in speed change units,

s = unit value of a speed change unit eliminated,

r =  $P/(100-P)$ , and

P = percentage of sum of travelers on the two alternate routes who elected to use the toll road.

The signs of the terms must be watched. If the free route is designated as route 1, then  $\Delta M$  is likely to be negative and  $\Delta T$  and  $\Delta D$  are likely to be positive because measured costs are less on the free route, whereas, time and driving comfort costs are generally greater.

$$\text{Let } u = \frac{1}{h},$$

then

$$u \log r = -\Delta M - t\Delta T - s\Delta D.$$

$$\Delta M = -u \log r - t\Delta T - s\Delta D. \quad (4)$$