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Vehicle Operation as Affected by Traffic Control and Highway Type

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Vehicle Operation as Affected by Traffic Control and Highway Type

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Contents

Operating Characteristics of a Passenger Car on Selected Routes

CARL C. SAAL, Chief, Vehicle Operations Section,
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The Bureau of Public Roads has made extensive use of instruments developed by the Committee on Vehicle Characteristics of the Highway Research Board to observe certain operating characteristics of a typical 1951-model passenger car. These instruments record for any trip the amount of time in seconds that a vehicle operates in various class intervals of speed, rate of deceleration, percentage of maximum intake manifold vacuum (roughly proportional to engine torque), and percentage of throttle opening. The total trip time and amount of fuel consumed in each class interval of speed are also recorded, making it possible to compute the average rate of speed and fuel consumption.

The typical passenger car was operated by the same test driver about 28,000 miles on nine distinct studies during 1951 and 1952. Five of the nine studies delt with operations over a high-speed freeway and over the parallel major highway. These studies, which involved the New Jersey Turnpike, two sections of the Pennsylvania Turnpike, the Maine Turnpike, and the Shirley Highway, were made primarily to determine the advantages with respect to vehicle operation that may result through the use of freeways instead of the parallel major highways and to show to what extent certain built-in characteristics of the vehicle are used in normal operation. The other four studies were of a special nature, made to evaluate the effect of traffic signals, sight distance, grade separation and traffic conditions on certain operation characteristics of the vehicle. In addition, special tests were conducted with other instruments to determine the fuel consumption and accelerating ability on individual grades.

A comparison between travel time on a high-speed freeway and on a parallel major highway revealed a considerable time saving from use of the freeway. In contrast, fuel consumption, measured at the travel speeds found on the freeways and other roads, indicated the use of the freeway resulted in a higher rate of fuel consumption for the test car in each case. Use of the freeways saved enough travel mileage to make the fuel consumption in gallons approximately the same for an average trip over either type of facility, even with the higher speed of travel on the freeway in four out of the five cases. The results of the measurement of the other vehicle characteristics reveal that no more than 60 percent of the maximum decelerating ability of the test car was used on any test run, and that the maximum engine torque and full throttle opening were used only a very insignificant portion of the time.

Useful results of an incidental nature are included in this report. Variation of fuel consumption with speed and gradient, and the variation of fuel consumption with rise and fall for various attempted speeds were determined for the test car. These relations are used in the report to evaluate the effect of different methods for reducing gradient and of methods for estimating the fuel consumed on a given section of highway. Other data contained in the report show the time and fuel required to accelerate from 0 to 70 miles per hour on various degrees of grade.

● A KNOWLEDGE of certain operating characteristics of motor vehicles is essential in the development of standards and specifications for highways and for vehicles that will provide for the safe and efficient movement of traffic. In order to obtain data on the operation of typical passenger cars under varying highway operating conditions, the Committee on Vehicle Characteristics of the Highway Research Board, assisted by industry and government, developed instruments to record for any trip the amount of time that a vehicle operates at various speeds, rates of deceleration, percentages of maximum engine torque, and percentages of full throttle opening; the total fuel consumption and the amount of fuel used at various road speeds; and the total trip time.

The Bureau of Public Roads has made extensive use of these instruments to determine how these vehicle characteristics for a typical passenger car are related to various types of highway operations. A representative passenger car was operated some 28,000 miles on nine distinct studies during 1951 and 1952. Five of the nine studies dealt with operations over a freeway and over a parallel major highway. The other studies were of a special nature made to evaluate the effect of traffic signals, sight distance, grade separation, and traffic congestion on the vehicle's operational characteristics.

This report will be concerned essentially with the results of the studies which involved freeway operation. However, it will cover briefly studies of a special nature and will include the results of special tests made to determine the fuel consumption and accelerating characteristics of the test vehicle on individual grades. The results reported here will supplement those obtained by other investigators with the same set of instruments.

Although the basic data should have use in the fields of highway economics and design and within certain areas of automotive engineering, it is cautioned that the data represent only the performance of one 1951-model passenger car operated by the same driver throughout the tests. It may be farfetched to consider the performance data as representative of the average performance of passenger cars operating in the general traffic. On the other hand, it is believed that the performance of the test car on highway sections of varying geometric design may be compared to establish a relation which will be fairly representative of the relative performance of the average passenger car. Also, the relations established between fuel consumption, speed, and other variables may be reliably used to determine the relative advantages of various methods of reducing grades and estimating the fuel consumed on a given highway section.

TERMINOLOGY

In order that there be a clear understanding of the discussions in this report, terms frequently used are here defined.

Freeway. A divided arterial highway for through traffic with full control of access and with grade separations at intersections.

Major Street or Major Highway. An arterial highway with intersections at grade and direct access to abutting property and on which geometric design and traffic control measures are used to expedite the safe movement of through traffic.

Overall Travel Time. The time of travel, including stops and delays except those off the traveled way.

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

Composite Performance. The performance in given terms for a round trip over a specified section of highway. (Composite gasoline consumption in gallons per mile is the total number of gallons of gasoline required by a vehicle to travel in both directions on a section of highway, divided by twice the length of the section in miles.)

Directional Performance. The performance in given terms in a single direction over a specified section of highway.

Road-User Benefits. The advantages or savings that accrue to drivers or owners through the use of one highway facility as compared with the use of another. Benefits are measured in terms of the decrease in road-user costs and the increase in road-user services.

Total Rise and Fall. The arithmetic sum of the vertical rise and fall in feet for any section of highway. (If a section of highway progressively rises 100 feet, falls 500 feet, rises 30 feet, and falls 10 feet, the total rise and fall will be 640 feet. The total rise and fall is the same regardless of the direction of travel.)

Rate of Rise and Fall. The total rise and fall for any section of highway divided by the length of section in hundreds of feet. (It is not to be confused with the percent of grade. It is equivalent to the average percent of grade only when either the rise or fall is 100 percent of the total rise and fall.)

Average Test Method. The driver travels at a speed which, in his opinion is representative of the speed of all traffic at the time, without trying to keep a balance in the number of passings.

Attempted-Speed Test Method. The driver attempts to maintain a specified speed over a section of highway, passing all vehicles that interfere with maintaining the specified speed, and exceeding the specified speed only during the passings.

Maximum Torque. The maximum engine torque at a specified engine speed or corresponding road speed.

PURPOSES OF REPORT

The specific purposes of this report are to (1) show some of the road user benefits that may result through the use of a freeway instead of a parallel major highway; (2) determine the extent to which certain built-in vehicle characteristics are used in normal operation; (3) establish basic relations between fuel consumption and highway gradient, and between acceleration and highway gradient; (4) evaluate several methods used to estimate the fuel consumed on a highway section; and (5) determine the relative advantages, in terms of fuel savings, of two methods commonly used to reduce gradients.

SUMMARY OF FINDINGS

The pertinent findings described below refer specifically to the operations of the test passenger car. Definite conclusions as to the overall performance of passenger cars in the general traffic cannot be formed from the results of tests on a single passenger car operated by the same driver on all tests. Only indications of the overall performance of passenger cars should be read into any of the findings.

1. For each of the five freeway studies, considering the total lengths, the test car would have had to travel over the freeway at a slower speed than the average overall travel speed reported for all passenger cars using the facility in order to realize the same rate of fuel consumption as observed on the parallel major highway. Therefore, if the test car were to maintain prevailing overall travel speeds on the comparable roads, the consumption per mile was higher on each freeway than on the parallel major highway.

2. A major highway must have a much greater rate of rise and fall or be much more congested than a parallel freeway in order to have a lower rate of consumption on the freeway when the vehicle is operated at the average overall travel speeds found on the two roads. For example, the consumption per mile at the prevailing average overall travel speeds was lower on the western section of the Pennsylvania Turnpike than on the highly urbanized section of the parallel route extending through Wilkinsburg and Pittsburgh.

3. A sizable time savings resulted in each case from the use of a freeway, instead of a major highway, at the average overall travel speeds found on the two roads.

4. Except in one case, the use of the freeway in preference to the parallel major highway saved enough travel mileage to make the fuel consumption in gallons approximately the same for a composite trip over either facility when the vehicle was operated at the average overall travel speeds found on the two roads.

5. The use of a freeway instead of a major highway, where the average overall travel speed on the freeway was below 40 miles per hour, as on the Pentagon network, for example, resulted in a sizable savings in gasoline during the peak traffic periods.

6. The percentage of time spent in braking was nearly zero on a freeway and very small on a major highway; however, the time spent in braking on a major highway was as much as 34 times greater than that spent on a freeway. The maximum rate of deceleration recorded on any test was about 60 percent of the potential rate of deceleration built into the car.

7. The maximum engine torque and the full throttle opening were used only a very small portion of the time on either a freeway or a major highway. Less than half of the potential torque and power were normally utilized on any test run. The average engine torque and throttle opening observed on a major highway was appreciably less than that observed on the parallel freeway at the average overall travel speeds found on the two roads.

8. The relations established between fuel consumption and rate of grade and between fuel consumption and rate of rise and fall were very similar in character. In general, the rate of consumption increases at a fairly uniform rate with an increase in grade or rate of rise and fall up to 6 per-

cent. Above 6 percent, the increase is at a faster rate.

9. A reduction of grades in excess of 6 percent resulted in appreciable savings in fuel consumption, whether or not the reduction produced a reduction in rise and fall. However, reduction of grades between 4 and 6 percent produced no substantial savings unless the grade reduction also reduced rise and fall. A reduction of 3- and 4-percent grades did not result in an appreciable savings, even if rise and fall was also reduced.

10. The use of the rate of total rise and fall of a section of highway to estimate the fuel consumption on the section was found to be as accurate as a more-complicated method that involves the consideration of each individual grade.

SCOPE OF THE STUDIES

Freeway Studies

In selecting the five pairs of test routes for studying some of the road-user benefits that might result from the use of freeways by passenger cars, an effort was made to cover as wide a range of highway conditions as possible in the eastern part of the United States. The five freeways selected for study were the New Jersey Turnpike, the middle section of the Pennsylvania Turnpike, the Maine Turnpike, the western section of the Pennsylvania Turnpike, and the Shirley Highway (in Virginia). Only the latter route was free of toll. The parallel major highway in each instance was the alternate route that would be commonly used to travel between the same termini.

Figures 1 through 5 show sketches of the general layout of the test routes for each study and the profiles for each pair of routes, except for the Maine Turnpike study. These profiles were plotted from elevations measured with an altimeter. It is to be noticed that each of the routes, except the western section of the Pennsylvania Turnpike, was divided into test sections by control points located at definite changes in the character of the profile or traffic flow. The operating characteristics of the test vehicle, within each section, were recorded at these control points.

All of the freeways were built approximately to the same design standards. The maximum grade was not over 3 percent in any case, and the rate of rise and fall varied from 0.8 for the New Jersey Turnpike to 1.4 for the two sections of the Pennsylvania Turnpike. It could be expected that the test car would perform about the same on each of the five freeways.

In contrast, each route paralleling a freeway afforded a conglomeration of surface types, pavement widths, curvature, and gradient. There was also considerable variation in the design characteristics between the various parallel routes. The rates of rise and fall varied from 0.9 for the route paralleling the New Jersey Turnpike to 3.3 for the route paralleling the middle Pennsylvania Turnpike. The parallel major highway and the turnpike had approximately the same rate of rise and fall in the case of the New Jersey and Maine studies. The rates of rise and fall for the routes paralleling the middle and western sections of the Pennsylvania Turnpike and the Shirley Highway were about 2.4, 1.4, and 1.3 times that for the respective freeway. In addition to the wide range in the character of the profiles, the routes paralleling the freeways differed materially from each other in other ways, which had a bearing on the results obtained. This can best be brought out by a brief description of each parallel major highway.

Generally, the parallel major highway in New Jersey was of four-lane construction with fair alinement, except for the southern section between control Points 1 and 2 (see Figure 1). This southern section was essentially of two-lane construction with poor alinement. The test car encountered traffic congestion particularly on Sections 1-2; within the numerous small municipalities that lie on the route from Control Point 1 to 6; on the bypass around Camden in Section 2-3; and on parts of the sections between Control Points 6 and 10 where the route passed through a highly urbanized area. The congestion was most severe from control Point 8 to 10, which extends from the east approach of the Pulaski Skyway to the George Washington Bridge.

In Maine, the parallel route was a two-lane highway with rather poor alinement for all except a short section near Portland. The test car was frequently slowed by passage through frequent municipalities varying in population from a few hundred to over 20,000.

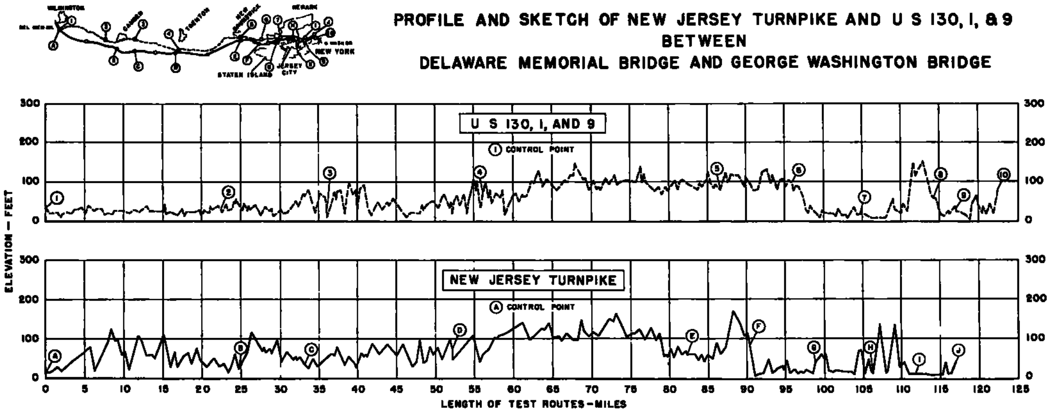

Figure 1.

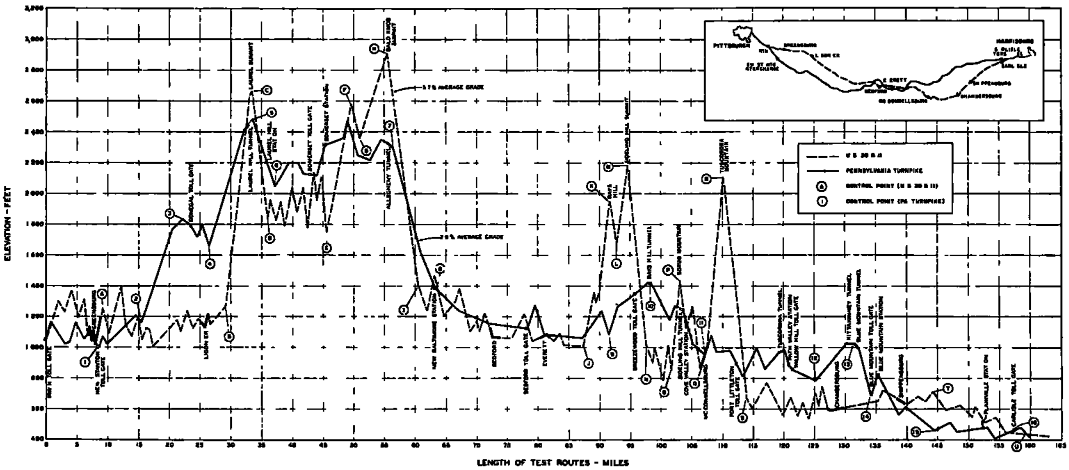

Figure 2.

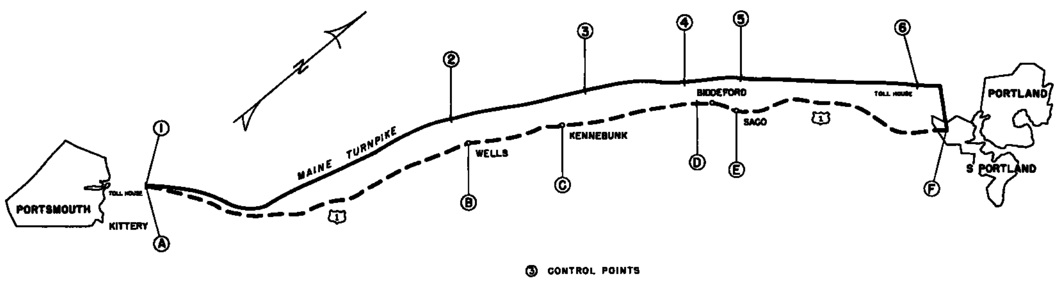

Figure 3.

The route paralleling the middle section of the Pennsylvania Turnpike generally consisted of two lanes varying in individual width from 9 to 12 feet. Only a small mileage had lanes wider than 10 feet. Narrow shoulders, sharp curves, and restricted sight distances were the rule. The greater portion of the route was paved with bituminous surface with high crown prevailing in many sections. The operation over this route may be classed as strictly rural, since there are only six towns of any size, the largest of which was about 17,000 population. Traffic congestion was only a minor factor in the results of tests obtained for this route. The important factors with respect to passenger-car operations were gradient and poor alinement.

The western portion of the Pennsylvania Turnpike bypasses Wilkinsburg, Pittsburgh, and an almost continuous string of municipalities which dot the north bank of the Ohio River between Pittsburgh and Rochester. The parallel major highway was principally urban for about 70 percent of its length.

made to supplement data previously obtained by tests of vehicle performance on an old road and subsequently on a complete relocation of improved alinement between a junction near Frederick and the city limits of Hagerstown, Maryland. The

In Virginia, US 1, which parallels the Shirley Highway, passes through Alex-

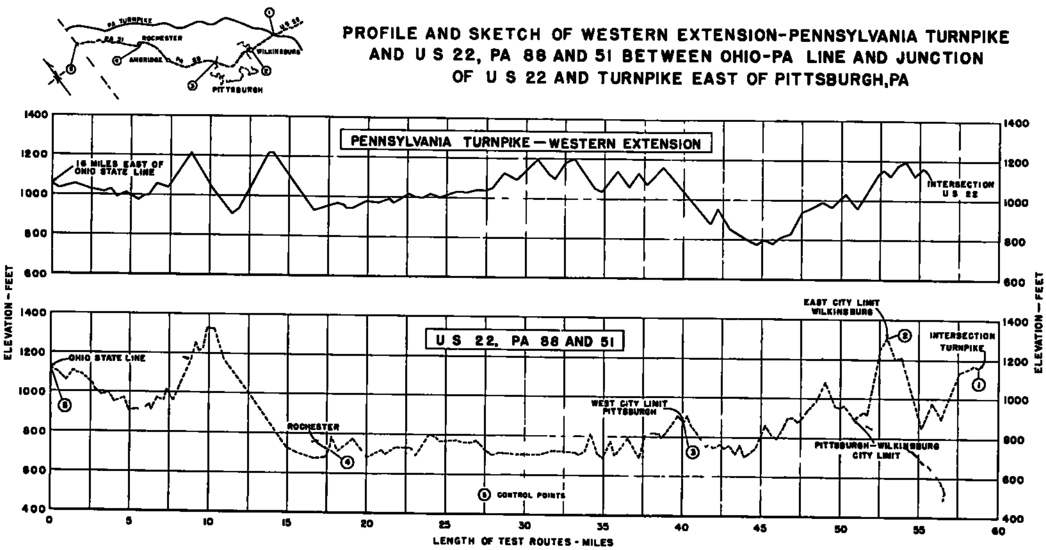

Figure 4.

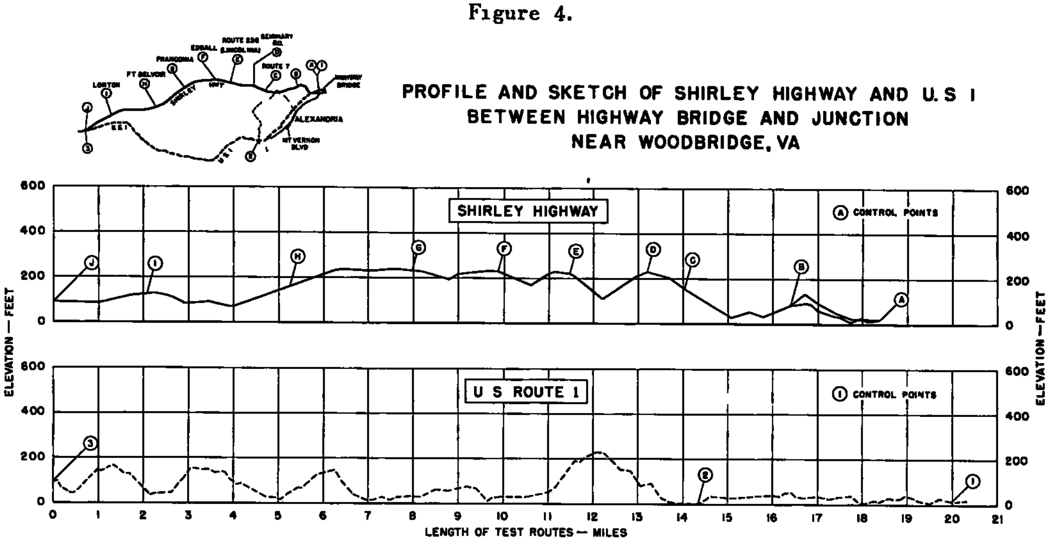

Figure 5.

for a maximum speed limit of 35 mph. or less. This route in the rural areas is a four-lane highway with fair alinement.

Special Studies

One of the four special studies was

andria and its environs, which constitute over 30 percent of the length of test route. Restricted speed zones also exist through areas of heavy roadside development and through a military reservation. Actually more than 50 percent of the route is zoned

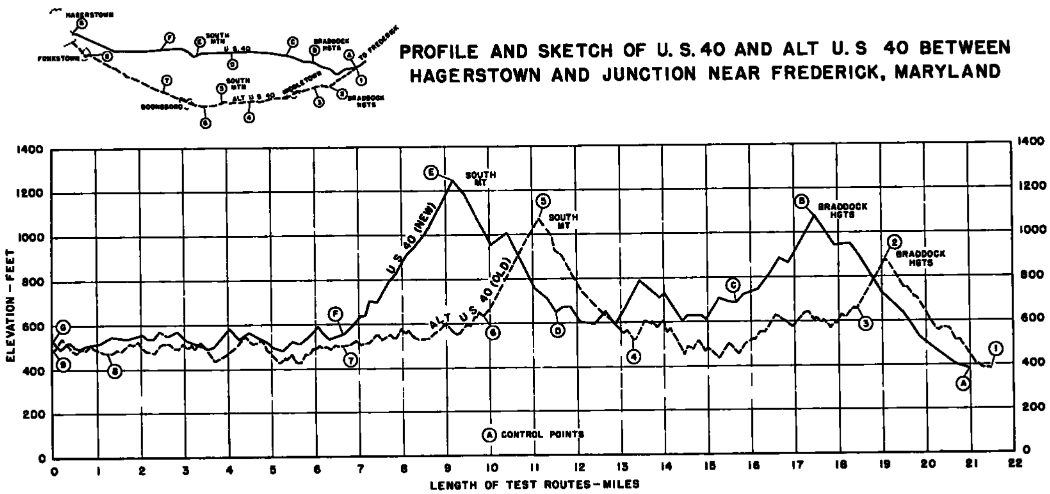

Figure 6.

sketch and profiles of the two test routes are shown in Figure 6. In length and rise and fall, there is little to choose between the two locations. The rates of rise and fall were 3.7 for the new road and 4.1 for the old road, the highest rates of all the test routes. Moreover, on each road, grades ranged as steep as 8 percent, and on each, heavy grades run a mile or more in length. The big difference between the two roads lies in the percentage of the total length of each that permits passing. On the old road 49.3 percent in one direction and 45.6 percent in the other, or nearly half of the total length, was marked for no passing. On the new road only 12.2 percent of the length in one direction and 11.6 percent in the other would not permit safe passing.

Another special study involved two possible routes between two bridges across the Potomac River at Washington, D. C., and Annandale, Virginia (see Figure 7). This study was made primarily to obtain average running times of passenger cars for use in a study (1) of the effect of travel time and distance on freeway usage. However, while the running times were being observed the other vehicle characteristics were also studied. The first leg of each route was identical, being a rather low-speed freeway operation (posted limit of

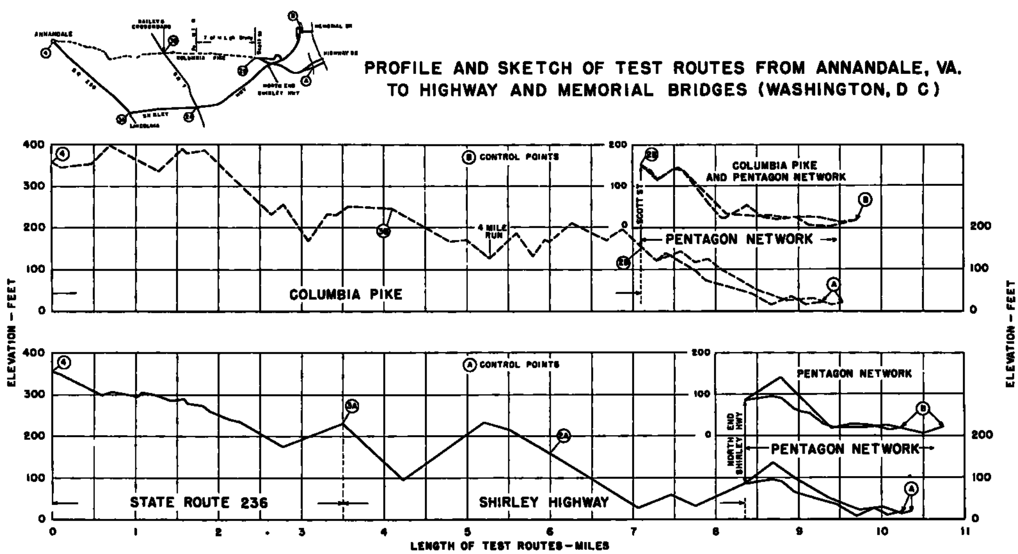

Figure 7.

VOC-1

VEHICLE OPERATING CHARACTERISTICS
BUREAU OF PUBLIC ROADS TESTS

Employing equipment developed by HRB Committee on Vehicle Characteristics

Test No. B-Run 2 **Date** October 23, 1951

Route U. S. 130, 1 and 9, Major highway parallel to New Jersey Turnpike

Remarks Section 1 - 2, Northbound
Deepwater to Thorofare, U. S. 130 before opening of Turnpike

SPEED

Counter No.	1	2	3	4	5	6	7	8	9	10	Total counts
Speed, MPH	0-5	6-8	9-11	12-18	19-23	24-35	36-46	47-56	57-68	69 & up	
Finish	36349	43778	22724	57671	63082	36613	32258	18835	46931	07078	
Start	36335	43777	22720	57650	63031	35894	31306	18487	46931	07078	
Difference	14	1	4	21	51	719	952	348	0	0	2110
% Total	0.7	1/	0.2	1.0	2.4	34.1	45.1	16.5	0	0	

GASOLINE CONSUMPTION

Counter No.	1	2	3	4	5	6	7	8	9	10	Total counts
Speed, MPH	0-5	6-8	9-11	12-18	19-23	24-35	36-46	47-56	57-68	69 & up	
Finish	33046	49290	59817	92727	60401	40136	99300	00050	51920	03729	
Start	33045	49290	59816	92723	60384	39833	98752	99769	51920	03729	
Difference	1	0	1	4	17	303	548	281	0	0	1,155
% Total	0.1	0	0.1	0.3	1.5	26.2	47.5	24.3	0	0	

BRAKING

Counter No.	1	2	3	4	5	6	7	8	9	10	Total counts
Deceleration	0-3	4-7	8-10	11-13	14-16	17-19	20-23	24-26	27-29	30 & up	
Finish	74418	29629	06203	02380	02206	02542	02141	06856	85677	03158	
Start	72309	29614	06203	02380	02206	02542	02141	06856	85677	03158	
Difference	2109	15	0	0	0	0	0	0	0	0	2124
% Total	99.3	0.7	0	0	0	0	0	0	0	0	

ENGINE TORQUE

Counter No.	1	2	3	4	5	6	7	8	9	10	Total counts
% Torque	Coast	0-10	11-21	22-32	33-43	44-55	56-66	67-77	78-88	89-100	
Finish	77642	79928	19508	14947	27422	41757	25848	21789	43770	08527	
Start	77588	79679	19103	14367	26790	41630	25776	21741	43751	08526	
Difference	54	249	405	580	632	127	72	48	19	1	2187
% Total	2.5	11.4	18.5	26.5	28.9	5.8	3.3	2.2	0.9	1/	

THROTTLE OPENING

Counter No.	1	2	3	4	5	6	7	8	9	10	Total counts
% Opening	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	90-100	
Finish	44203	84569	82488	98040	41216	31988	26359	23185	29305	46465	
Start	44164	83742	81669	97610	41189	31988	26359	23185	29305	46465	
Difference	39	827	819	430	27	0	0	0	0	0	2142
% Total	1.8	38.6	38.2	20.1	1.3	0	0	0	0	0	

ODOMETER

Finish 8367.45	
Start 8345.20	
Trip Mileage	22.25

CLOCK

Finish 5:52 P.M.	
Start 5:17 P.M.	
Trip Time (Seconds)	2100

MASTER COUNTER

Finish 15014	
Start 12891	
Total Counts (Seconds)	2123

Trip Average Speed 37.7 **MPH**

Trip Average Gas Consumption 19.3 **MPG**

1/ Less than 0.05%

Figure 8.

40 mph.) on the Pentagon network. One of the routes followed the Columbia Pike to Annandale, on which there were numerous intersections at grade and on which there was heavy traffic congestion during the morning and evening peaks. The other route, included a section of the Shirley Highway and Virginia Route 236. About two thirds of the latter route was a freeway as compared to about one fourth of the route to Annandale by way of the Columbia Pike.

A third study was made for the Regional Highway Planning Committee for Metropolitan Washington to aid in determining the need for constructing an interchange ramp at Fourteenth Street, S. W., and Maine Avenue in Washington, D. C., which would eliminate an at-grade intersection for traffic desiring to make a left turn from

Maine Avenue into Fourteenth Street. A grade separation had been built at this location, but the one intersection leg was retained at grade because the ramp had to pass through a corner of the Bureau of Engraving and Printing Building. Only travel time and fuel consumption were measured on this study during both the peak and off-peak traffic periods.

The fourth special study was made on a 2-mile section of Columbia Pike between Four Mile Run Drive and Scott Street as indicated on Figure 7. Tests were made during peak and off-peak periods when there were two traffic light installations, and then repeated when eleven additional traffic actuated signals had been installed within the same section.

Special Tests

In addition to the Freeway and special studies that have just been described, tests were made to determine the fuel consumption and accelerating ability of the test car on individual grades of 0.0, 2.84, 6.0, and 8.0 percent. The grades were 1.00, 0.40, 0.284 and 0.50 miles in length, respectively. All of these grades were at elevations of 900 feet or less, and all except the 8.0-percent grade were surfaced with a pavement of portland-cement concrete. The 8-percent grade was paved with a high-type bituminous concrete.

TEST PROCEDURE

Freeway and Special Studies

The instruments installed in the test car were described in detail in a previous report (2). For that reason, this report will consider only the type of information collected and the procedures employed.

A typical field data sheet is shown in Figure 8 for the southernmost section of the major highway paralleling the New Jersey Turnpike. The recording apparatus consisted of five banks of 10 counters each, an electric clock, and a master time counter. These counters were actually arranged in the same pattern as the field data sheet. Each count represented 1 second on the banks of counters for speed, braking, engine torque and throttle opening; and 0.001 gal. on the bank of counters for gasoline consumption. Each counter of a bank represented a class interval of the particular item being studied. The units of the class intervals were miles per hour for speed and gasoline consumption, feet per second per second for braking, and percent for engine torque and throttle opening. The range in the class intervals for each bank of counters is shown in Figure 8.

The time read from the electric clock was used to check the proper functioning of the master counter and, in turn, the time indicated by the master counter was used to ascertain that all counters of a given bank were functioning properly. In Figure 8, it is seen that the total time counts shown opposite the counter banks checked closely with the master time counter. Likewise, the trip time from the electric clock compares closely with that from the master counter. As indicated, the end result was an average rate of speed and gasoline consumption, and the percentage of the time spent in each range of speed, deceleration, and percentage of maximum torque and full throttle opening, and the percentage of gasoline used in the various speed ranges. The time recorded on the master time counter was used to compute the average speed.

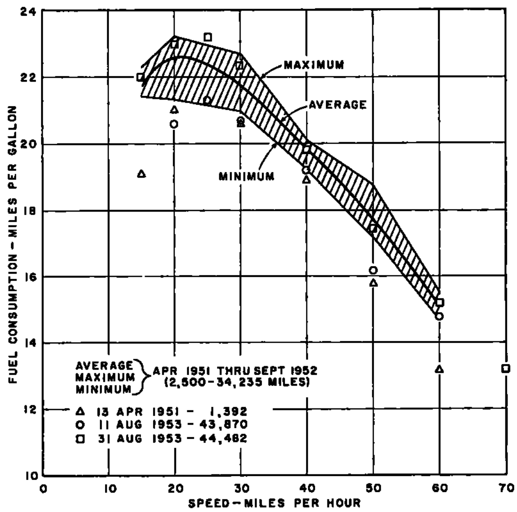

Figure 9. Fuel calibration with burette of 1951 Pontiac Six Sedan on 1-mile level section in third gear for various sustained speeds.

It is to be understood that engine torque was not directly recorded. Rather, the engine torque was assumed to be proportional to the pressure existing in the intake manifold. The intake-manifold-vacuum instrument consisted of a metal bellows to which was attached a calibrated spring and a swing arm that passed over a sector divided into contact segments representing ranges in vacuum. These ranges in vacuum were assigned engine torque values in percentage of maximum torque, as shown in Figure 8. The maximum torque referred to in this instance roughly approximates the maximum for the engine speed or corresponding road speed at the instant of recording. It is not to be confused with the peak engine torque. The percentage values can be roughly converted to pound-feet of torque or pounds of tractive effort by assuming an average maximum torque for the entire range of engine speed involved.

The "average" test method was used in those cases where the traffic volume was dense enough for the driver to reliably approximate the speed of all traffic at a given instant. Where the average test method was not feasible, test runs were made on a particular section at three or more attempted speeds so that the rate of fuel consumption could be interpolated for an average running speed of all passenger cars obtained from other sources. Attempted speeds greater than 60 mph. were not possible, because the fuelmeter did not have sufficient volume to supply the flow of fuel required to negotiate existing grades at higher speeds.

Three test runs were made over each test route in each direction at each attempted speed for all except two of the studies. For the intersection study at Maine Avenue and 14th Street, Washington, D. C., 12 test runs were made in the off-peak period and 26 test runs in the peak period. For the traffic light study on Columbia Pike (see Figure 7), four and sixteen test runs were made before the installation of additional traffic lights during the off-peak and peak periods respectively; six and eighteen test runs were made after the installation during the off-peak and peak periods, respectively. The test runs were scheduled so that a particular test section or route would be traveled at different times during the period of study.

Fuel Calibration of Test Car

In order to maintain the fuel characteristics of the test car at approximately the same level throughout the period of the study, calibration tests were conducted before and after most of the studies. The fuel consumption of the test car was checked with a burette on a measured mile located on the Shirley Highway. Test runs were made in both directions over the section at speeds of 15, 20, 25, 30, 40, 50 and 60 mph.

The results of 13 such calibration tests are shown in Figure 9. The average consumption rates in miles per gallon, between April 1951 and September 1952 when the odometer readings ranged from 2, 500

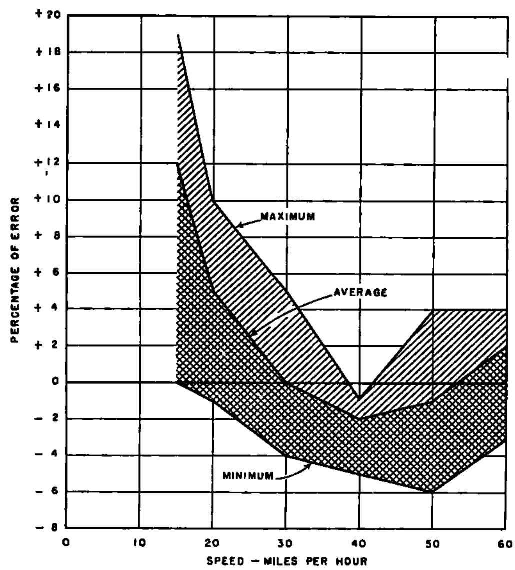

Figure 10. Calibration of fuel meter with burette on 1-mile level section for various sustained speeds during period April 1951 through April 1952.

to 34, 235 miles, is shown by the smooth curve. The variation of the rates of consumption from the average during this period are indicated by the maximum and minimum values, each of which are connected by a series of straight lines. The percentage of variation from the average ranged from 1. 4 to 6. 2 percent. In view of this rather small variation, which was obtained by frequent engine tuneups, no attempt was made to correct the results for changing fuel-consumption characteristics. The triangular-shaped points are the rates of consumption observed before the start of the project, when there was 1, 392 miles on the odometer and the engine was apparently either not properly broken in or tuned.

In the fall of 1953, about a year after the completion of the freeway and special studies, it was planned to make some special grade tests with the same passenger car. The vehicle was calibrated at that time, and the rates of consumption, indicated by the circular points on Figure 9, were found to be less than the minimum rates observed for the previous period of tests. For this reason, the engine was given a tune-up that included the replacement of spark plugs, and overhaul of carburetor and distributor. The rates of consumption observed after this tune-up, indicated on Figure 9 by the square-spared symbols, fell generally on or above the average curve and well within the band created by the maximum and minimum lines.

Calibration of Instruments

The accuracy of the instruments for measuring deceleration, throttle opening, and intake-manifold vacuum were checked only a few times during the entire series of studies. However, the speedometer was calibrated frequently against the test-car speedometer, which had been calibrated with an accurate speedometer actuated by a test wheel. It was found that the class intervals originally established for a given bank of counters did not vary appreciably during the tests.

The volumetric fuelmeter, which was of the positive-displacement type, was calibrated in conjunction with the fuel calibration of the test vehicle before and after most of the studies. The results of the calibration tests, made with a burette that could be read to the nearest cubic centimeter, are shown in Figure 10. These tests were conducted on a 1-mile level section of highway at the indicated speeds. A plus error indicates that the fuelmeter reading in gallons was less than the true consumption, the opposite for a negative error.

Since speed is proportional to the rate of flow, it is evident in Figure 10 that the fuelmeter did not give the same accuracy for all rates of flow. The fuelmeter was purposely adjusted to give the higher degree of accuracy for flow rates comparable to those for sustained speeds of 30 mph. or more, because rates of flow in that range were normally required. The average error was decidedly on the plus side for the lower flow rates and slightly on the negative side for the higher flow rates. It increased at a fast rate as the flow rate decreased below the flow rates comparable to speeds of 30 mph. or less. The fuelmeter reading will result in a rate of consumption that is considerably lower than the true rate, if the engine operates at or near idle speed for an appreciable portion of the total running time.

The results of the calibration tests were used to correct the observed rates of consumption to a common base, if it could be determined that the flow rates were consistently high. Correction factors could not be developed for those tests with considerable low-speed operation, since it was not possible from the speed record obtained on the counters to ascertain whether the vehicle was accelerating with a high flow rate or idling with a low flow rate. The variation in the fuelmeter accuracy during a study was not of sufficient magnitude to affect materially the relative fuel consumption for two parallel routes studied at approximately the same time. However, it was necessary to correct to a common base, in order to relate the results of the various studies, since the accuracy of the fuelmeter is shown in Figure 10 to vary appreciably during the period of the studies.

Special Test Procedures

In order to determine the relation between fuel consumption, speed, and degree of gradient, the test car was operated at sustained speeds of 15, 20, 25, 30, 40, 50, 60 and 70 mph. on 0.0-, 2.84-, 6.0- and 8.0-percent grades. For each sustained speed, at least three runs were made in both directions over a given grade. The fuel consumed by the test car was measured with a graduated burette connected in the fuel line between the car fuel pump and the carburetor. Fuel was pumped by the regular fuel pump into the burette and by an electric fuel pump from the burette to the carburetor. The temperature of the fuel in the burette was recorded for each run. Because the range of these temperatures was small, no attempt was made to correct the observed volumes to a standard base.

The accelerating ability of the test car was measured on the same four grades. Test runs were made with wide-open throttle in each direction on each test section, accelerating through each gear from a standing start to about 40 mph., and in direct gear (third) from a speed of 20 mph. to the highest practicable speed. A minimum of two test runs were made for each condition of test.

The acceleration was determined from a record of time and distance, which was made on a wax-coated paper fed through a chronograph at a constant speed of about 5 inches per second. Time was recorded on the tape at 1-sec. intervals by a small electrically actuated hammer wired to a timer. The record of distance was obtained by means of a rotating contact housed on a test wheel and driven by an odometer shaft. The rotating contact opened and closed an electrical circuit at every 2 feet of travel, causing a stylus of the chronograph to make a crenelated trace on the moving tape.

A time-distance curve was plotted for each test run. This curve was differentiated by the mirror method at frequent points to determine instantaneous speeds. After the first differentiation a time-speed curve was plotted and differentiated to obtain approximate instantaneous rates of acceleration. From these results, it was possible to derive relations for each grade that could be used to determine the distance and time required to accelerate between any two speeds, and the instantaneous acceleration rates for given speeds.

In conjunction with the acceleration tests, the fuel consumed while accelerating was measured with the burette at frequent points during each test run. When the burette was read, the chronograph tape was marked by pushing a switch wired to a stylus. It was then possible to determine the speed at the instant the burette was read. The result was an accumulative record of fuel consumption by speed which could be used to find the fuel consumed when accelerating between any two speeds.

<u>Test Car Specifications</u>

The pertinent specifications of the test car are listed below:

Make and Model - 1951 Pontiac 6, 4-door sedan
Transmission - 3 speed synchromesh
Weight: Front - 1920 pounds
Rear - 2080 pounds
Total - 4000 pounds
Bore and stroke - 3 $^{9}/_{16}$ x 4 inches
Piston displacement - 239.2 cu. in.
Compression ratio - 6.5
Transmission ratios:
1 st ------- 2.67 to 1
2 nd ------ 1.66 to 1
3 rd ------ 1 to 1
Rear axle ratio - 4.10 to 1
Maximum gross horsepower - 96 at 3400 rpm.
Maximum net horsepower - 90 at 3400 rpm.
Maximum gross torque - 191 at 1200 rpm.
Maximum net torque - 186 at 1,000 rpm.

The following horsepower and torque data were taken from curves in the Manufacturer's Shop Manual:

Road speed in 3rd gear mph.	Maximum gross horsepower	Maximum gross torque lb.-ft.
20	34	185
25	44	191
30	54	191
35	63	189
40	72	186
50	85	178
60	94	163
70	96	143
80	91	119

SUMMARY OF BASIC DATA

The results for each test route are summarized in Table 1. This summary will form the basis for a discussion of the operation characteristics of the test car on freeways and the parallel major highways, and for a brief résumé of the findings for the four special studies. It contains the average rates of speed and fuel consumption, the average engine torque, and the average throttle opening for each test method, ("average" or "attempted speed"). The average engine torque and throttle opening were determined by weighting the percentage of the total trip time recorded in each class interval with the midpoint value of the given class interval.

Correction factors derived from the results of the fuel-meter-calibration tests were applied to the observed rates of consumption to produce the values shown in Table 1; except where no correction was warranted, and except in the cases of intersection and traffic-light studies. In the latter instances, reliable factors could not be developed, because the test car oper-

TABLE 1

SUMMARY OF AVERAGE COMPOSITE PERFORMANCE OF TEST VEHICLE ON VARIOUS ROUTES

Test Route	Length	Rise and fall	Date of tests	Period of study[1]	Speed		Fuel consumption (corrected)	Braking			Time factor	Average engine torque	Average throttle opening
					Attempted	Average		Percent time		Max decel-eration			
								0-3 ft/sec²	over 3 ft/sec²				
	miles	ft/100 ft			mph	mph	mpg	percent	percent	ft/sec²	sec/100 mi	percent	percent
Delaware Bridge to	116 3	0 8	Apr. 52	8 a m	40	39 4	18 6	100 0	[2]	8-10	2 6	29 0	17 1
George Washington Bridge via				to	50	48 6	17 2	100 0	[2]	8-10	2 4	33 8	21 1
New Jersey Turnpike				6 p m	60	58 1	15 4	99 9	0 1	11-13	5 3	45 4	34 1
Delaware Bridge to	122 2	0 9	Oct 51	8 a m	"Avg "[3]	38 3	17 4	98 1	1 9	14-16	181 2	31 4	25 7
George Washington Bridge via			Apr 52	to	do	40 7	17 2	98 2	1 8	14-16	159 0	34 8	20 3
US 130, 1 & 9				6 p m									
Carlisle Interchange to	148 7	1 4	Dec 51	8 a m	40	40 2	18 8	100 0	[2]	11-13	2 7	27 0	14 7
New Stanton Interchange via			&	to	50	49 0	16 8	99 9	0 1	8-10	7 6	33 5	17 8
Pennsylvania Turnpike			June 52	6 p m	60	57 1	15 1	99 7	0 3	11-13	18 5	42 6	31 3
Carlisle to Greensburg, Pa	149 4	3 3	Dec 51	8 a m	30	30 6	17 6	99 4	0 6	11-13	70 5	30 2	–
via US 11 & 30			&	to	40	38 0	16 6	99 0	1 0	11-13	93 5	32 6	–
(including larger towns)			June 52	6 p m	50	42 7	15 6	97 6	2 4	14-16	196 8	36 3	–
Carlisle to Greensburg, Pa	140 3	3 4	Dec 51	8 a m	30	30 6	17 5	–	–	–	–	–	–
via US 11 & 30			&	to	40	40 3	16 5	–	–	–	–	–	–
(excluding larger towns)			June 52	6 p m	50	46 0	15 5	–	–	–	–	–	–
Kittery to Portland, Maine	41 8	1 2	Aug 52	8 a m	40	39 8	19 3	–	–	–	–	–	–
via Maine Turnpike				to	50	49 0	16 5	–	–	–	–	–	–
				6 p m	60	58 8	14 9	–	–	–	–	–	–
Kittery to Portland, Maine	43 8	1 3	Aug 52	Weekday	"Avg "[3]	36 4	17 9	–	–	–	–	–	–
via US 1				Weekend	do	35 1	17 7	–	–	–	–	–	–
Pittsburgh Interchange to	55 2	1 4	July 52		40	40 3	19 0	–	–	–	–	–	–
Ohio State Line via					50	49 8	17 4	–	–	–	–	–	–
Pennsylvania Turnpike				8 a m	60	58 8	15 7	–	–	–	–	–	–
				to									
			Oct 52	6 p m	40	39 9	19 1	–	–	–	–	–	–
					50	49 9	17 1	–	–	–	–	–	–
					60	58 8	15 6	–	–	–	–	–	–
Pittsburgh Interchange to	58 5	2 0	Dec 51		"Avg "[3]	26 4	16 7	–	–	–	–	–	–
Ohio State Line via US 22	[4](40 9)	2 1	Dec 51	8 a m	do	23 8	16 2	–	–	–	–	–	–
Pa Alt 19, 88, & 51	[5](17 6)	1 9	Dec 51	to	do	35 8	18 2	–	–	–	–	–	–
(through Pittsburgh)	[4] 40 9	2 1	July 52	6 p m	do	25 9	16 7	–	–	–	–	–	–
	[4] 40 9	2 1	Oct 52		do	25 1	16 6	–	–	–	–	–	–
	[5] 12 9	2 7	July 52		do	18 3	14 9	–	–	–	–	–	–
Washington, D C (High-	18 4[7]	1 3	Dec 51		"Avg "[3]	49 8	17 9	99 7	0 3	8-10	19 7	38 8	24 7
way Bridge) to Woodbridge,			Mar 54		do	50 9	17 2	–	–	–	–	–	–
Va via Shirley Highway	14 1	1 1	Mar 54	Off-	55	53 2	18 8	–	–	–	–	–	–
			Mar 54	peak	50	49 5	17 9	–	–	–	–	–	–
			Mar 54		40	40 6	19 6	–	–	–	–	–	–
			Mar 54		30	30 8	21 1	–	–	–	–	–	–
Washington, D C (High-	20 3	1 7	Dec 51	Off-	"Avg "[3]	31 8	18 9	98 9	1 1	11-13	120 7	31 0	17 7
way Bridge) to Woodbridge,	(6 0)[8]	1 0	Dec 51	peak	do	23 6	18 1	97 9	2 1	11-13	318 8	28 7	12 4
Va via US 1	(14 3)[5]	1 9	Dec 51		do	40 7	19 2	99 5	0 5	8-10	43 4	32 7	21 2
Washington, D C (High-	20 4	1 7	Dec 51	Off-	"Avg "[3]	36 4	18 8	98 7	1 3	11-13	127 0	31 8	20 6
way Bridge) to Woodbridge,	(6 1)[8]	1 0	Dec 51	peak	do	28 8	17 7	97 3	2 7	11-13	335 8	30 3	17 1
Va via Mt Vernon Blvd	(14 3)[5]	1 9	Dec 51		do	40 7	19 2	99 5	0 5	8-10	43 4	32 7	21 2
and US 1													
Frederick to Hagerstown,	21 0	3 7	July 51		30	32 3	18 5	100 0	[2]	4-7	1 2	26 8	23 1
Md via New US 40			July 51		40	40 9	17 5	100 0	0 0	–	0 0	30 3	26 2
			Sept 52	8 a m	40	39 6	17 5	99 1	0 1	4-7	7 2	–	–
			July 51	to	50	49 4	16 2	99 7	0 3	27-29	22 8	34 2	29 4
			Aug 52	6 p m	50	48 5	15 8	–	–	–	–	–	–
			Sept 52		50	47 7	16 0	99 7	0 3	8-10	21 6	–	–
			July 51		60	53 4	14 8	99 6	0 4	8-10	28 7	41 0	33 9
			Sept 52		60	54 6	14 6	98 8	1 2	8-10	79 1	–	–
Frederick to Hagerstown,	21 5	4 1	July 51	8 a m	[9]	35 9	16 6	99 2	0 8	8-10	82 4	29 9	20 7
Md via Old US 40				to									
				6 p m									
Washington, D C (High-	9 4	2 4	July 51	Peak	"Avg "[3]	26 6	15 4	97 5	2 5	8-10	315 3	29 3	20 1
way Bridge) to Annandale, Va				Off-peak	do	33 1	17 8	98 2	1 8	8-10	219 1	28 5	20 4
via Columbia Pike													
Washington, D C (High-	10 3	1 8	July 51	Peak	"Avg "[3]	40 0	16 4	98 6	1 4	8-10	120 8	31 4	26 2
way Bridge) to Annandale, Va				Off-peak	do	43 9	17 7	99 5	0 5	4-7	38 7	33 8	28 8
via Shirley Highway													
Washington, D C (Memorial	9 7	2 4	July 51	Peak	"Avg "[3]	26 5	15 4	97 3	2 7	11-13	366 9	30 0	19 5
Bridge) to Annandale, Va via				Off-peak	do	34 3	17 4	98 6	1 4	11-13	149 9	29 1	22 5
Columbia Pike													
Washington, D C (Memorial	10 5	1 8	July 51	Peak	"Avg "[3]	41 0	16 4	99 7	0 3	4-7	28 5	29 9	26 2
Bridge) to Annandale, Va via				Off-peak	do	45 3	17 7	98 6	1 4	8-10	114 0	35 1	29 6
Shirley Highway													
Washington, D C (1301 Maine	0 23	0 2	Oct 51	Peak	"Avg "[3]	8 9	9 6	–	–	–	–	–	–
Avenue to Inlet Bridge)				Off-peak	do	18 4	13 1	–	–	–	–	–	–
Arlington, Va (Columbia Pike	2 00	3 1	April 52	Peak	"Avg "[3]	21 4	13 3	–	–	–	–	–	–
from 4 Mile Run Drive to				Off-peak	do	26 1	16 3	–	–	–	–	–	–
Washington Blvd			Aug 52	Peak	do	21 5	14 2	–	–	–	–	–	–
Underpass)				Off-peak	do	24 9	14 0	–	–	–	–	–	–

[1] A minimum of three round trips was made over each test route spaced to cover the period indicated
[2] Less than 0 05 percent
[3] "Average" test method used
[4] Urban traffic conditions
[5] Rural traffic conditions
[6] Through Wilkinsburg and Pittsburgh, Pa
[7] Speed limit posted 40 mph for 1 9 miles, 50 mph for 2 4 miles, and 55 mph for 14 1 miles
[8] Through Alexandria
[9] Attempting to drive speed profile for passenger cars observed before opening of New US 40

ated a high percentage of the time at speeds less than 30 mph.

Also included in Table 1 are data showing the percentage of the time spent in braking, the maximum class interval in which time was recorded, and a time factor. The vehicle was considered to be braking when the deceleration rate was more than 3 ft. per sec. per sec. The time factor is a ratio of the number of seconds recorded in class intervals of over 0 to 3 ft. per sec. per sec. and the length of the test route in hundreds of miles.

Average results like those shown in Table 1 were tabulated for each of the test sections of a given route. Also included were the various time distributions and the fuel distribution by speed. Such a mass of data were collected that for this report it was considered practical to analyze and discuss only the average performance summarized in Table 1 and summaries of some typical examples of the data (see the appendix). However, the complete basic data have been placed on file in the offices of the Highway Research Board and are available for reference by the Committee on Vehicle Characteristics and others requesting this material.

FREEWAY STUDIES

Speed and Fuel Consumption Compared

The rates of fuel consumption and speed, shown in Table 1 for the freeways and the parallel highways, are compared in Figures 11 and 12. The term "average" over a bar indicates that the rate of fuel consumption or speed was obtained by driving the average test method. In Figure 11, the three major highways are classed as rural, although they pass through numerous urban areas in New Jersey and Maine. The two parallel routes, identified in Figure 12, are composed of a substantial percentage of urban mileage.

For the studies involving the New Jersey, Maine, and western section of Pennsylvania Turnpike, the freeway was run with attempted speeds of 40, 50, and 60 mph., and the parallel routes by the average test method. In the case of the middle Pennsylvania Turnpike study, both routes were run with the "attempted speed" test method; the freeway at speeds of 40, 50 and 60 mph., and the major highway at speeds of 30, 40 and 50 mph. The average test method was used for both the Shirley Highway and its parallel routes.

For purposes of this report it was assumed that the speed and fuel consumption rates observed on US 11 and US 30 in Pennsylvania for the attempted speed of 50 mph. approximate the performance that would have been obtained by the average test method. This was necessary because the traffic on many parts of this route was too light to use the average method of test. It is also noted that the values plotted in Figure 11 for this route were based on the results which include the operations in the six major towns. The exclusion of these towns, as shown in Table 1, increased the average speeds, especially for the attempted speed of 50 mph., but did not materially change the rates of fuel consumption. The performance through each of the six towns, the largest of which is Chambersburg, with a 1950 population of 17,212, is shown in Table E (see appendix).

From the comparisons in Figures 11 and 12, except for the Shirley Highway, it is possible to obtain an idea of the overall travel speeds that must be driven on the freeways to obtain a rate of fuel consumption that approximately equals that obtained by the average test method on the parallel route. In the case of the New Jersey and Maine turnpikes the average speed is indicated to be less than 50 mph., and in the case of the middle and western sections of the Pennsylvania Turnpike it lies between 50 and 60 mph. By actual interpolation of curves drawn to show the relation between the rates of fuel consumption and the average speeds obtained for the attempted speeds, the speeds which gave equivalent consumption rates were 48, 46, 54 and 53 mph., respectively, for the turnpikes in the order previously mentioned.

It is interesting to rationalize the reasons why the New Jersey and Maine turnpikes must be traveled at slower speeds than the two sections of the Pennsylvania Turnpike in order to match the rates of consumption observed on the respective parallel routes. The principal reasons undoubtedly are because the middle Pennsylvania Turnpike saves considerable more rise and fall than the New Jersey and Maine turnpikes (which save practically none), and because the western Pennsylvania Turnpike saves considerable more traffic congestion with the resultant stop-and-go driving. The western section also has a small advantage over the parallel route in the degree of rise and fall.

tained with the average test method, which was designed to produce an overall travel speed that approximated that of all passenger cars using the facility.

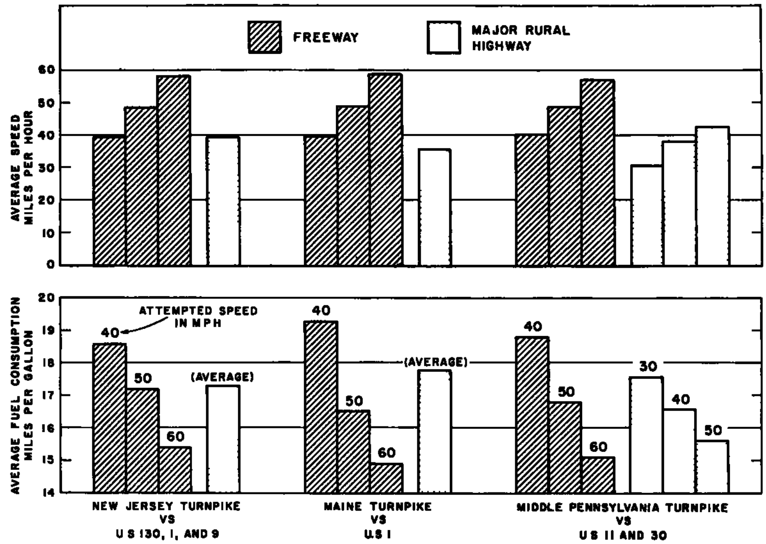

Figure 11. Fuel consumption and speed on freeways compared with that on parallel major rural highways.

Referring again to Figures 11 and 12, it is seen that the average speed approximates the attempted speed in each instance. This fact indicates that little traffic interference was encountered on the turnpikes up to an attempted speed of 60 mph. Also, the rate of fuel consumption for a given attempted speed was nearly the same for each of the four turnpikes. For instance, for an attempted speed of 60 mph., the consumption rate was 15.4, 14.9, 15.1 and 15.6 mpg. for the New Jersey, Maine, and Pennsylvania turnpikes, respectively.

Some Road-User Benefits Evaluated

The road-user benefits in terms of travel time and fuel consumption that might result through the use of the freeway by the test car are indicated in Table 2. For this analysis the test car was assumed to travel at the average overall travel speeds of passenger cars on the four turnpikes, which are reported to be in the neighborhood of 55 mph. for the New Jersey and Maine turnpikes, and 57 mph. for the two sections of the Pennsylvania Turnpike. The rate of fuel consumption shown in Table 2 for each of the four routes was based on these average speeds. In all other instances, the results used were obtained with the average test method, which was designed to produce an overall travel speed that approximated that of all passenger cars using the facility.

The travel time ratios in Table 2, which are based on the average overall travel speeds and the indicated lengths of the test routes, show that the use of the freeway resulted in a considerable time saving in each case. The ratios range from 0.44 for the western Pennsylvania Turnpike to 0.73 for both the New Jersey and Maine turnpikes. In other words the travel time on the freeway was 44 and 73 percent of that required on the respective parallel routes.

In contrast, the fuel consumption ratios which are computed from the average rates of consumption and the distances shown in Table 2 show that the test car would burn slightly more fuel on three of the freeways than on the parallel highways. This is indicated by a ratio greater than 1.00. The rates of consumption were higher on the freeway in each instance, although the difference was less than 1 mpg. for the two sections of the Pennsylvania Turnpike. However, because of the saving in distance attributed to the use of the freeway, the consumption in gallons was about the same over each pair of routes with the possible exception of the Maine study, in which case the ratio was 1.08, an 8-percent advantage to the parallel major route.

In connection with the western Pennsylvania Turnpike study, it is seen in Table 1 that the rate of consumption through the cities of Wilkinsburg and Pittsburgh, a distance of 12.9 miles, average 14.9 mpg.; and that through the 40.9-mile section, classed as urban, it averaged 16.5 mpg. A comparison of these rates with the one shown in Table 2 for the parallel freeway definitely shows that it requires considerable traffic congestion to increase the rate of consumption above that found at the normal overall travel speeds on the Pennsylvania Turnpike. Of course, a considerable saving in fuel would be realized by operating at lower speeds on the turnpike.

attempted speed of 60 mph. was spent in the 57-to-68 mph. group. In the case of the parallel major highway, the time was distributed over a much wider range, indicating a great number of speed changes.

There was also a great difference between the time distribution for the route paralleling the New Jersey Turnpike (Figure 13) and that for the route paralleling the western Pennsylvania Turnpike (Figure 14). In the former instance, about 9.6 percent of the time was spent at speeds below 24 mph. In the latter instance, the corresponding value was 38.9 percent. This wide variation in the time distributions helps to explain the differences be-

TABLE 2

COMPARISON BETWEEN FUEL CONSUMPTION AND TRAVEL TIME OF TEST VEHICLE ON FREEWAY AND ON PARALLEL MAJOR HIGHWAY

Study	Average overall travel speed		Average rate of fuel consumption		Length		Freeway-major highway ratio	
	Major highway a	Freeway b	Major highway	Freeway c	Major highway	Freeway	Travel time	Fuel consumption
	mph.	mph.	mpg.	mpg.	miles	miles		
New Jersey Turnpike	38 3	55	17 4	16 0	122.2	116 3	0 66	1 03
Pennsylvania Turnpike (Middle)	[d] 42.7	57	15.6	15.1	[e] 163.0	[e] 159.7	0.73	1.01
Maine Turnpike	35 7	55	17.8	15.7	43.8	41 8	0 62	1 08
Pennsylvania Turnpike (Western)	26.4	57	16 7	16 0	58 5	55 2	0 44	0.99
Shirley Highway (Virginia)	33.8	[f] 50	18 9	[f] 17.9	20 3	18 4	0 61	0.96

[a] Except for Pennsylvania Turnpike (Middle), result of using the "average" test method.
[b] Except for Shirley Highway, based on available reports on average over-all travel speed of passenger cars.
[c] Except for Shirley Highway, interpolated from results determined by "attempted speed" test method
[d] Result of driving "attempted speed" of 50 miles per hour.
[e] Distance between Middlesex and Irwin Interchanges.
[f] Result of using "average" test method.

In the case of the New Jersey and western Pennsylvania studies, the parallel major highway was traveled before and after the opening of the turnpike. The results of these before-and-after studies are shown in Table 1. They indicate that the opening of the turnpikes did not materially affect passenger-car operations on the older routes.

Time and Fuel Distribution by Speed

Two typical examples of the great contrast between vehicle operation on a freeway and on a major highway are shown in Figure 13 for the New Jersey routes and in Figure 14 for the western Pennsylvania routes. In each of the two turnpike examples, about 98 percent of the time for the

tween the time and fuel consumption ratios shown in Table 2 for the two sets of routes.

The distributions of time shown in the upper portions of Figures 13 and 14 are compared with the distribution of fuel in Figure 15. An interesting point is the small percentage of fuel that was consumed below a speed of 24 mph. On the route through Pittsburgh where the average speed was 26.4 mph. only 23.9 percent of the fuel was burned below a speed of 24 mph. About 10 percent of the time was spent in the 0-to-5 mph. class interval and only 2.5 percent of the fuel was used in the same class interval.

Use of Built-in Vehicle Characteristics

One of the purposes of the study was to

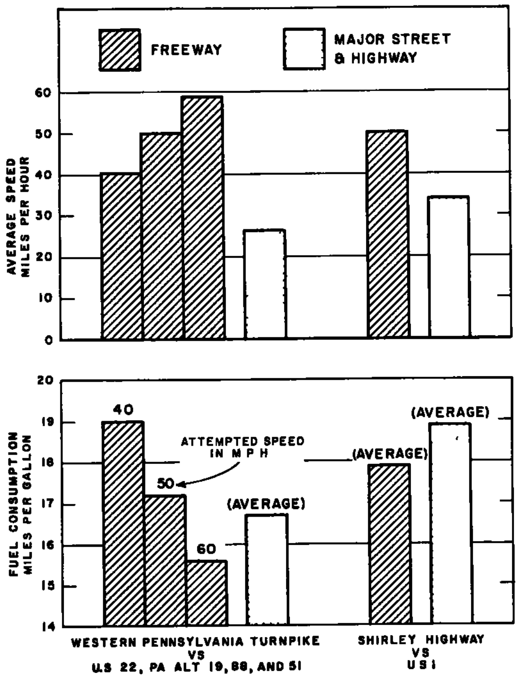

Figure 12. Fuel consumption and speed on freeways compared with that on parallel major streets and highways with a sizeable percentage of mileage in urban areas.

determine to what extent certain built-in vehicle characteristics were used in normal operation. The manner of conducting the tests precludes the use of speeds as a factor in this respect, except for the average runs made on the parallel major highways. The percentage of time spent in each range of deceleration, engine torque and throttle opening for the attempted speeds of 60 mph., however, do indicate to some degree the normal use of brakes and power at average speeds slightly greater than the average overall travel speed of normal freeway traffic.

On the test routes which were operated with the average test method, the 57-to-68-mph. class interval was the highest in which any time was recorded. The percentage of time in this class interval was less than 0.1 percent except for US 130, US 1 and US 9 in New Jersey and the Shirley Highway in Virginia, where it was 8.0 and 7.4 percent, respectively.

The most surprising results are probably those shown for the use of the brakes. It is seen that the percentage of time spent in braking was practically nothing for the freeways and rather insignificant for the parallel highways. The maximum deceleration recorded was in the range of 14 to 16 ft. per sec. per sec. Since the test vehicle by actual stopping distance tests

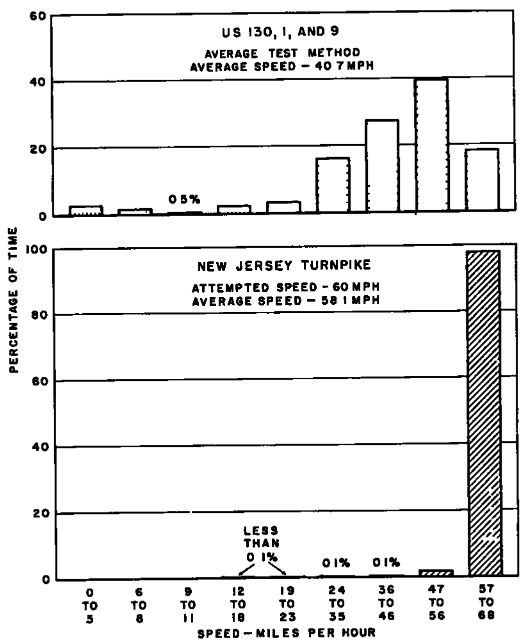

Figure 13. Time distribution by speed groups for New Jersey Turnpike and parallel major highway.

was capable of an average deceleration rate of 25.3 ft. per sec. per sec., only about 60 percent of the built-in braking force was used during any test.

Even though there was little time spent in braking on any route, a comparison of the time factors does indicate a sizable advantage for the freeways in this respect. For example, the time factor on the New Jersey Turnpike for an attempted speed of 60 mph. was 5.3 as compared with one of 181.2 for the parallel route before the opening of the turnpike.

The average values of composite engine torque and throttle opening shown in Table 1 indicate that only a small portion of the built-in torque and power were normally utilized on any of the tests. This is emphasized by the time distributions shown in Figures 16 and 17 for the three tests with the highest average engine torque and throttle opening. Time was seldom recorded in the highest two class intervals of engine torque (more than 77 percent) or in any class interval of throttle opening above 50 percent.

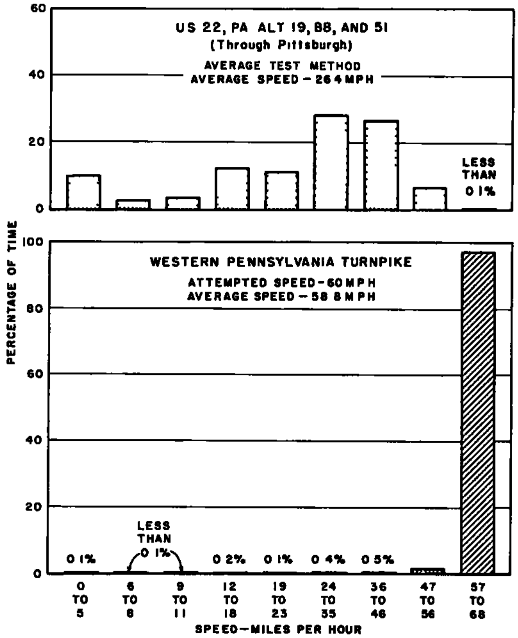

Figure 14. Time distribution by speed groups for Pennsylvania Turnpike and parallel major highway.

The results shown in Figures 16 and 17 were observed on three test routes with decidedly different profile characteristics. Operations on the New Jersey Turnpike were most consistent as indicated by about 75 percent of the time being spent in the engine torque range of 33 to 55 percent and

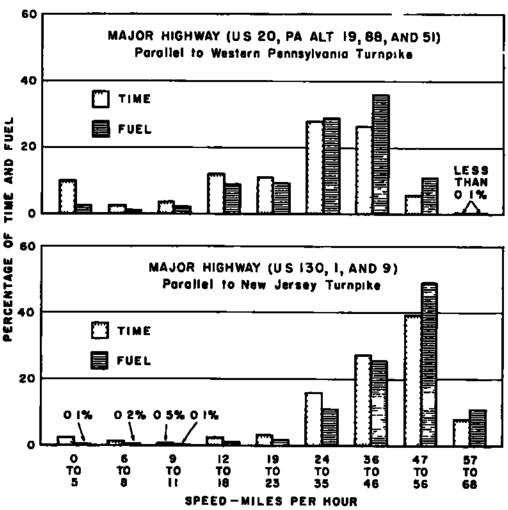

Figure 15. Comparison between time and fuel distribution by speed groups for major highways parallel to New Jersey Turnpike and western Pennsylvania Turnpike.

about 90 percent of the time in the throttle opening range of 20 to 39 percent. In contrast, the time was distributed over a much wider range of both percentage of engine torque and throttle opening in the case of US 40, on which there is a series of long steep grades.

Based on the data contained in Table 1 and on the average overall travel speeds shown in Table 2, the average engine torque and throttle opening observed on a major parallel highway was appreciably less than the average values observed on the corresponding freeway. For example, the average engine torque was 31.4 percent on the US 130, US 1 and US 9 in New Jersey and 41.2 percent by interpolation on the New Jersey Turnpike.

RÉSUMÉ OF SPECIAL STUDIES

US 40 in Maryland

From a study made in 1947 between Hagerstown and Frederick, Maryland, it was found that the average speed of passenger cars was 33.6 mph. on the old section of US 40 before the opening of the new section, and 42.5 mph. on the new section. For this reason the fuel consumption was measured on the old section attempting to drive the average speed of 33.6 mph. in accordance with the operating practices recorded at the time of the earlier tests. It is seen in Table 1 that the average rate of fuel consumption was 16.6 mpg. on the old section at an average speed of 35.9 mph. This rate compares with one of 17.1 mpg. determined for the average speed of 42.5 mph. by interpolating the rates measured on the new road for attempted speeds of 40 and 50 mph. The elimination of congestion created mostly by slow moving trucks on steep grades appeared to result in a slight saving in fuel consumption.

Washington, D. C., to Annandale, Virginia

The results are included in this report only for reference use, since the original purpose of the study (1) has already been served. The route which led to Annandale by way of the Shirley Highway was far superior in average speed especially during the peak traffic period. Also, the rate of consumption by way of Shirley Highway was lower during the peak period, 16.4

mpg. as compared with 15.4 mpg., but approximately the same during the off-peak period.

ing results for Section 2B-3B were 30.9 mph. and 17.5 mpg. during the off-peak period and 19.7 mph. and 14.0 mpg. during the peak period.

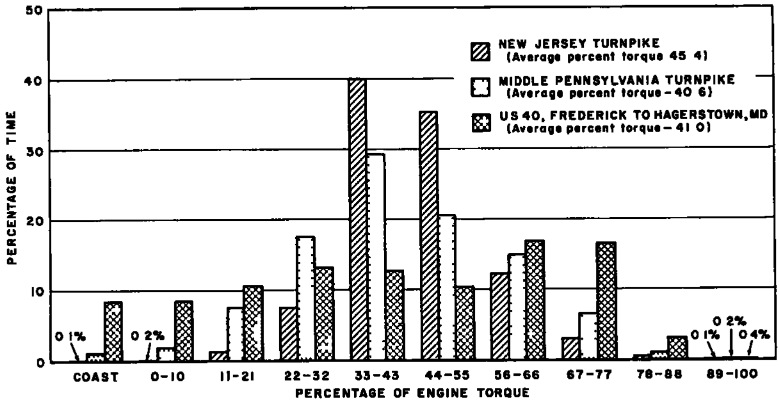

Figure 16. Time distribution by percent engine torque compared for attempted speed of 60 mph. on three test routes with different profile characteristics.

The average composite performance of the test vehicle on the various sections of these routes is shown in the appendix. The results may be used to make some interesting comparisons between urban operations on freeways and roads with intersections at grade. For illustration, the results shown for Section A-2B on the Pentagon network, and for Section 2B-3B on Columbia Pike will be used. On the former section, the off-peak results for speed and fuel consumption were 33.7 mph. and 18.0 mpg.; the peak results were 28.7 mph. and 17.6 mpg. The correspond-

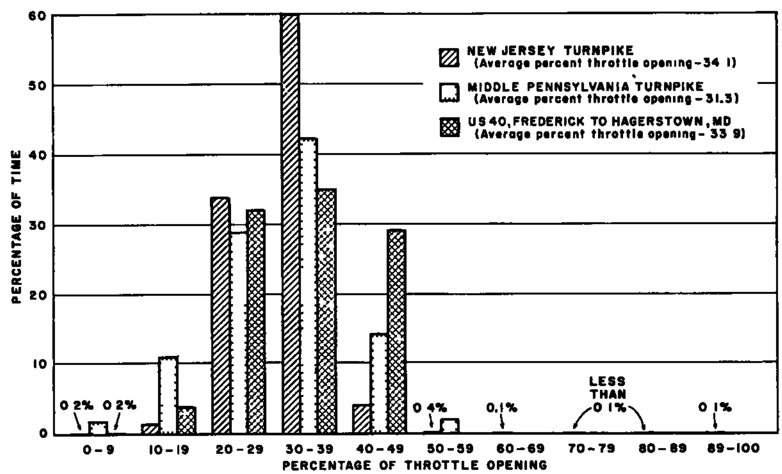

Figure 17. Time distribution by percent throttle opening compared for attempted speed of 60 mph. on three test routes with different profile characteristics.

The performance was not greatly reduced by heavier traffic on the freeway section, whereas it was materially reduced in the case of the section with intersections at grade. Also, the difference between the performance on the two sections during the off-peak period was not great. It appears that sizable savings in fuel consumption may result in peak traffic periods through use of freeways under urban conditions of operation. This is, of course, contrary to the findings already reported for high-speed operations on freeways.

Intersection Study

The results need no explanation, except that the true rate of fuel consumption was probably somewhat higher than the value in Table 1 because of the characteristics of the fuelmeter shown in Figure 10. It was previously pointed out that the observed rates of consumption were shown in Table 1 because reliable correction factors could not be derived for this predominantly low-speed operation.

Traffic Light Study

These tests were made before and after the installation of 11 traffic actuated signals on the most congested section of the Columbia Pike. The results are summarized in Table 1. The comments just made about the rates of fuel consumption for the intersection study apply also to this study.

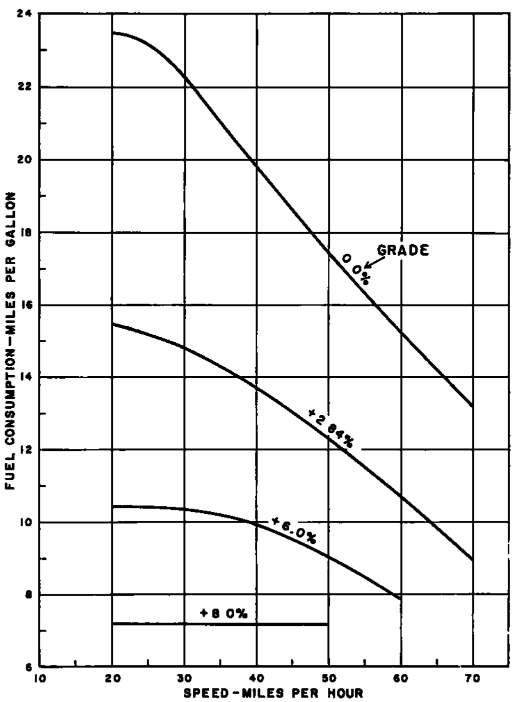

Figure 18. Fuel consumption on ascending uniform grades at sustained speeds.

The pertinent findings were that the average overall travel speed was reduced about 5 percent and the rate of consumption was increased about 12 percent during the off-peak periods. During the peak period, the average overall travel speed was about the same but the rate of consumption was lower by about 6 percent. The purpose of the signal installation was to facilitate the cross traffic with as little interference to the main traffic flow as possible. If the movement of the cross traffic were expedited, as it would be reasonable to assume, it appeared that the purpose of the installation had been accomplished within reasonable limits.

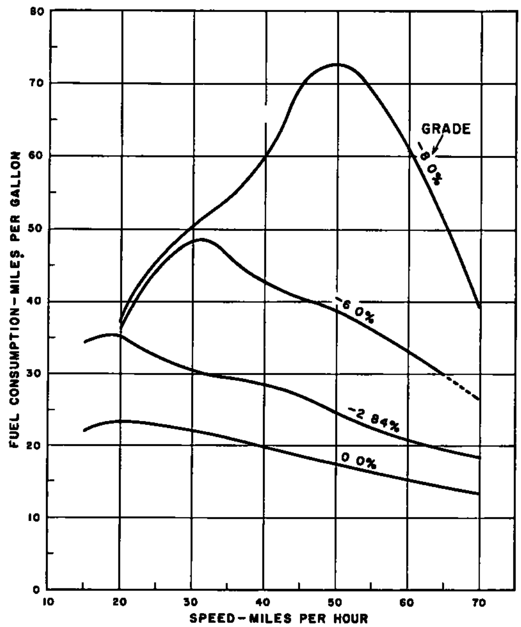

Figure 19. Fuel consumption on descending uniform grades at sustained speeds.

GRADE TEST

Fuel Consumption Rates

In order to add to the scant data that have been reported for the fuel characteristics of modern passenger cars on a wide variety of gradients, the test car was tested on grades ranging from 0 to 8 percent. The vehicle was operated in direct gear at sustained speeds ranging from 15 to 70 mph. and was accelerated in various gears from a standing start to the highest practicable speed.

The rates of consumption in miles per gallon for the sustained speeds are shown in Figure 18 for ascending, and Figure 19 for descending four uniform grades. The composite consumption, which combines the results shown in Figures 18 and 19, is

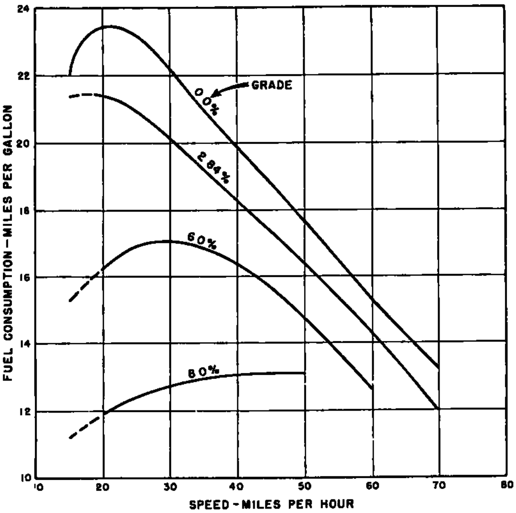

Figure 20. Composite fuel consumption on ascending and descending uniform grades at sustained speeds.

given in Figure 20. For the uphill tests, the consumption decidedly increased at a slower rate with speed as the grade increased. This is due, in most part, to the fact that the air resistance which increases approximately with the square of the speed is constant for each grade and becomes a smaller portion of the total resistance to motion as the grade increases. It is seen that the consumption remains almost constant for ascending the 8-percent grade and actually decreased slightly with speed for the composite relation. The test car could not sustain a speed of 65 mph. on a 6-percent grade or 55 mph. on the 8-percent grade.

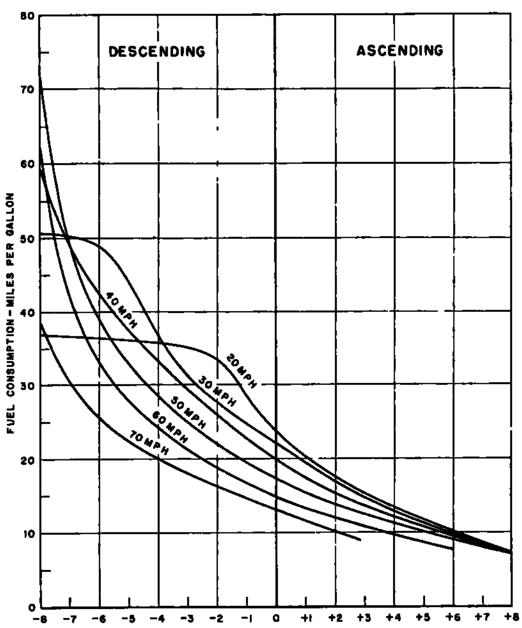

Figure 21. Directional fuel consumption for various sustained speeds as related to gradient.

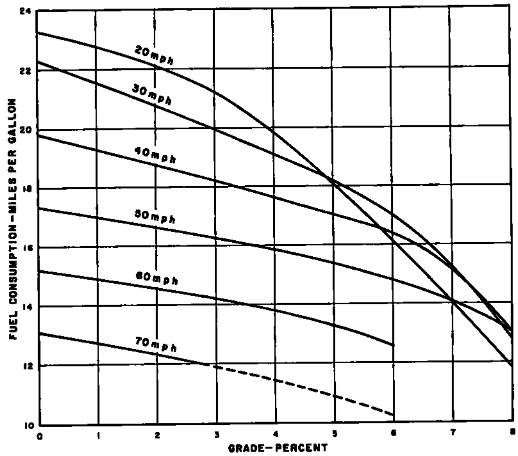

Figure 22. Composite fuel consumption in terms of miles per gallon for various sustained speeds related to gradient.

The directional fuel consumption shown in Figures 18 and 19 and the composite fuel consumption shown in Figure 20 are replotted in more usable form in Figures 21 and 22, respectively. From these curves it is possible to determine easily the fuel consumption for any degree of gradient at a given sustained speed. Considering the composite consumption, the interesting point is that the rate of consumption increases at a fairly uniform rate with an increase in grade up to a grade of 6 percent for all except the 20-mph. sustained speed. Above 6 percent the increase is at a faster rate indicating that the reduction of grades above 6 percent should result in a saving in fuel consumption for the test vehicle, even if the rise and fall is not reduced. The relations for composite consumption shown in Figure 22 are plotted in terms of gallons per mile in Figure 23 for later use in this report.

Accumulative fuel curves for accelerating on the level and on various plus and minus grades with full throttle from a standing start to 30 mph. are shown in Figure 24. Two gear shifts were made, one at 17 mph. and one at 29 mph. Actual-

TABLE A

SUMMARY OF AVERAGE COMPOSITE PERFORMANCE OF TEST VEHICLE ON VARIOUS SECTIONS OF NEW JERSEY TURNPIKE BETWEEN DELAWARE BRIDGE AND GEORGE WASHINGTON BRIDGE

Date of Tests, April 1952

Section	Length	Rise and fall	Average speed	Fuel consumption	Braking: Percent time 0-3 ft/sec²	Braking: Percent time over 3 ft/sec²	Braking: Max deceleration	Braking: Time factor	Average engine torque	Average throttle opening
	miles	ft./100 ft	mph	mpg	percent	percent	ft./sec²	sec./100 mi	percent	percent
Attempted Speed, 40 mph										
A - B	24 7	0 9	39 4	19 2	100 0	0 0	0-3	0 0	28 0	15 6
B - C	8 3	0 8	39 0	18 7	100 0	0 0	0-3	0 0	28.7	15 1
C - D	18 9	0 8	39 6	18 8	100 0	0 0	0-3	0 0	29.1	15 4
D - E	30 2	0 7	39 0	18 5	99 9	0 1	8-10	7 3	29.1	20 7
E - F	8 1	0 8	39 8	18 5	100 0	0 0	4-7	1 9	29 0	17 4
F - G	8 6	0 8	39 3	18 5	99 9	0 1	8-10	7 6	29 2	17 7
G - H	7 1	0 8	39 7	18 1	100 0	0 0	0-3	0 0	30 3	18 1
H - I	5 7	1 8	39 9	18 2	100 0	0 0	0-3	0 0	30 0	18 2
I - J	4 7	0 5	39 8	17 7	100 0	0 0	0-3	0 0	30 9	21 0
Total(A-J)	116 3	0 8	39 4	18 6	100 0	0 0	8-10	2 6	29 0	17 1
Attempted Speed, 50 mph										
A - B	24 7	0 9	48 5	17 6	100 0	0 0	4-7	0 6	33 1	22 4
B - C	8 3	0 8	48 2	17 2	100 0	0 0	0-3	0.0	33 3	23 1
C - D	18 9	0 8	48 9	17 3	100 0	0 0	4-7	0 8	33 9	22 1
D - E	30 2	0 7	48 6	17 1	100 0	0 0	8-10	2 2	33 9	19 8
E - F	8 1	0 8	49 1	17 2	100 0	0 0	0-3	0 0	33 5	19 4
F - G	8 6	0 8	48 4	17 2	99 9	0 1	8-10	5 8	34 3	20 2
G - H	7 1	0 8	48 9	17 0	99 8	0 2	4-7	14 1	34 9	20 8
H - I	5 7	1 8	48 7	17 4	99 9	0 1	8-10	6 1	32 5	20 7
I - J	4 7	0 5	48 6	16 6	100 0	0 0	0-3	0 0	34 8	20 5
Total (A-J)	116 3	0 8	48 6	17 2	100 0	0 0	8-10	2 4	33.8	21 1
Attempted Speed, 60 mph										
A - B	24 7	0 9	58 2	15 3	99 9	0 1	8-10	4 7	46 3	43 8
B - C	8 3	0 8	57 4	15 1	100 0	0 0	0-3	0 0	45 4	31 3
C - D	18 9	0 8	58 0	15 5	100 0	0 0	11-13	3 4	45 2	31 1
D - E	30 2	0 7	58 3	15 4	99 9	0 1	8-10	4 5	44 8	31 9
E - F	8 1	0 8	58 9	15 6	99 9	0 1	8-10	6 2	44 4	31 3
F - G	8 6	0 8	57 8	15 6	99 9	0 1	11-13	5 8	44 7	31 5
G - H	7 1	0 8	58 4	15 3	99 7	0 3	4-7	16 2	45 3	31.8
H - I	5 7	1 8	57 7	15 2	99 8	0 2	8-10	14 9	47 0	31 8
I - J	4 7	0 5	57 7	14 8	100 0	0 0	0-3	0 0	46 3	32 2
Total (A-J)	116 3	0 8	58 1	15 4	99 9	0 1	11-13	5 3	45 4	34 1

TABLE B

SUMMARY OF AVERAGE COMPOSITE PERFORMANCE OF TEST VEHICLE ON VARIOUS SECTIONS OF US 130, 1, AND 9 IN NEW JERSEY BETWEEN DELAWARE BRIDGE AND GEORGE WASHINGTON BRIDGE USING "AVERAGE" TEST METHOD

Section	Length	Rise and fall	Average speed	Fuel consumption	Braking: Percent time 0-3 ft/sec²	Braking: Percent time over 3 ft/sec²	Braking: Max deceleration	Braking: Time factor	Average engine torque	Average throttle opening
	miles	ft /100 ft	mph	mpg	percent	percent	ft /sec²	sec/100 mi	percent	percent
October 1951 Before opening of New Jersey Turnpike										
1 - 2	22 25	0 3	37 3	18 2	98 9	1 1	14-16	101 1	29 9	23 6
2 - 3	13 62	0 9	38 0	16 9	97 6	2 4	11-13	220 3	31 6	24 8
3 - 4	20 24	1 2	46 1	17 6	98 6	1 4	11-13	111 2	33 3	28 0
4 - 5	30 35	0 9	45 3	17 7	98 7	1 3	11-13	107 1	34 3	28 1
5 - 6	9 17	1 1	40 6	17 8	98 0	2 0	8-10	174 5	31 1	27 1
6 - 7	8 88	0 7	30 0	16 2	96 2	3 8	11-13	450 4	29 8	24 2
7 - 8	9 40	0 9	35 2	18 8	98 8	1.2	8-10	117 0	28.6	25 6
8 - 9	2 74	0 9	25 5	16 2	96 7	3 3	14-16	474 5	30 1	23.4
9 - 10	5 56	1 2	24 3	16 3	95.9	4 1	11-13	611 5	29 2	23 1
Total (1-10)	122 2	0.9	38 3	17 4	98 1	1.9	14-16	181 2	31 4	25 7
April 1952 After opening of New Jersey Turnpike										
*1 - 2	22 25	0 3	37.9	18 0	98.9	1 1	11-13	106 7	31 9	18 0
2 - 3	13 62	0 9	37 8	16 8	96 6	3 4	14-16	317 5	34 0	20 1
3 - 4	20 24	1 2	45 9	17 2	98 9	1 1	8-10	82 8	36 3	22 4
4 - 5	30 35	0 9	49 7	16 9	99 1	0 9	11-13	65 9	39 0	25 4
5 - 6	9 17	1 1	42.3	16 8	97 0	3 0	11-13	242 6	36 5	21 8
6 - 7	8 88	0 7	34 5	17 3	97 4	2 6	8-10	270 3	32 2	16 9
7 - 8	9 40	0 9	40 7	17 5	98 9	1 1	8-10	95 7	34 9	19 4
8 - 9	2 74	0 9	29.0	16 9	97 2	2 8	8-10	346 7	32.9	15 4
9 - 10	5 56	1 2	27 0	17 1	96 5	3 5	11-13	463.1	31 2	14 2
Total (1-10)	122 2	0.9	40 7	17 2	98 2	1 8	14-16	159 0	34 8	20 3

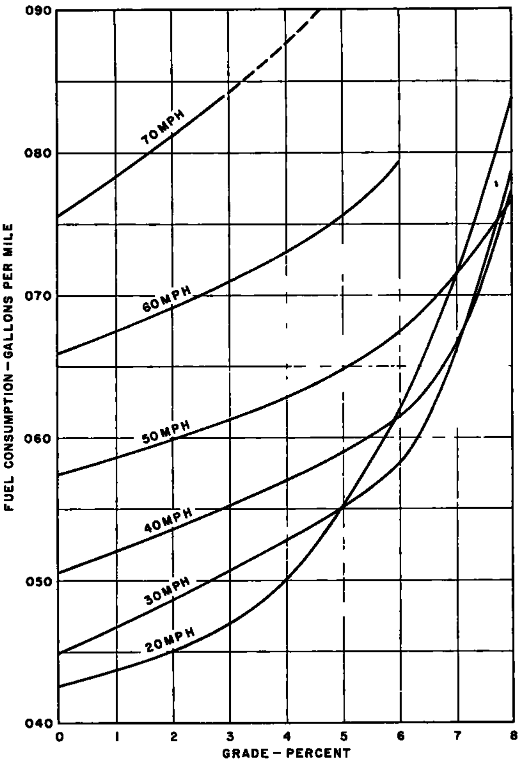

Figure 23. Composite fuel consumption in terms of gallons per mile for various sustained speeds as related to gradient.

ly the vehicle operated in third (direct) gear only from 29 to 30 mph. Similar relations for accelerating in third gear from 20 mph. to the highest practical speed are shown in Figure 25. Since the fuel consumption is accumulated with speed, it is possible to determine from these data the fuel consumed for accelerating between any two given speeds.

These data should have application to the problem of estimating the cost savings that might accrue to the users of passenger cars by the elimination of traffic congestion or other interruptions to the smooth flow of traffic, which cause the driver to accelerate from a reduced speed to the desired running speed. An example would be the economic analysis of the congestion caused by slowly moving trucks on hills.

Another useful value of fuel consumption obtained for the test car was the fuel consumed while idling. The consumption at an idling engine speed of approximately 460 rpm. was 0.4 gal. per hour. At an engine speed of 600 rpm. it was about 0.5 gal. per hour.

Acceleration Rates

The distance required to accelerate with full throttle between any two speeds can be determined from the curves shown in Figure 26 for accelerating through first and second gears from a standing start to

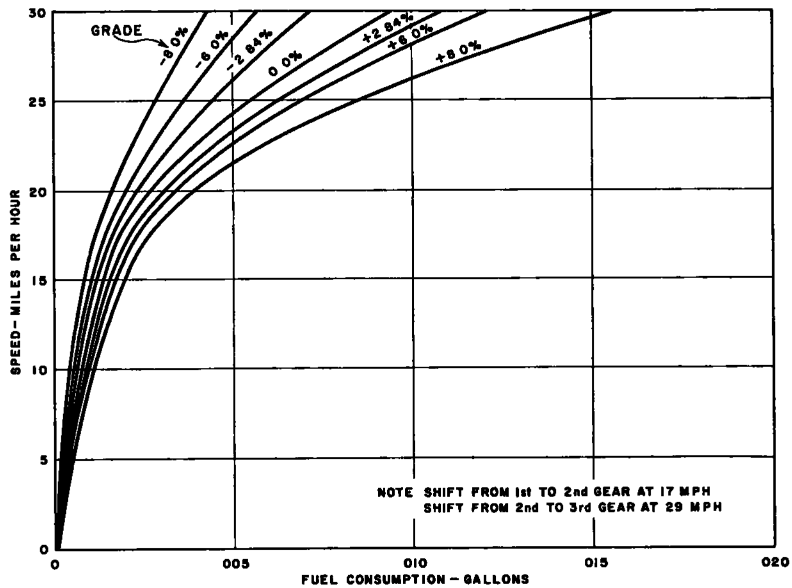

Figure 24. Fuel required to accelerate with full throttle through all transmission gears from a standing start to 30 mph. on various upgrades and downgrades.

30 mph., and in Figure 27 for accelerating in third gear from 20 mph. to the highest practicable speed. For example, to obtain the distance required to accelerate up a 6-percent grade from 30 to 50 mph., the accumulative distance of 350 feet at 30 mph. is subtracted from the accumulative distance of 1,800 feet at 50 mph. The answer is 1,450 feet.

Similar relations between speed and accumulative time are shown in Figure 28 for the same plus and minus grades. The time required to cover the distance of 1,450 feet obtained in the above example

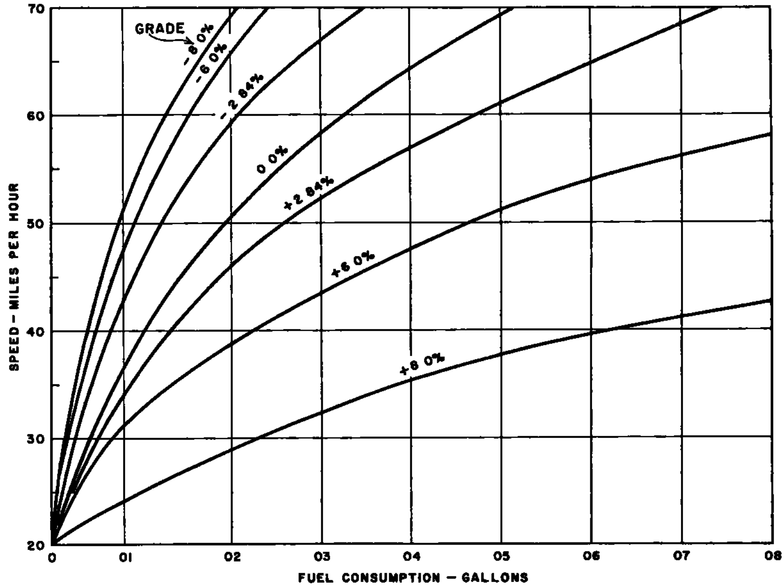

Figure 25. Fuel required to accelerate with full throttle in third gear from 20 mph. to higher speeds on various upgrades and downgrades.

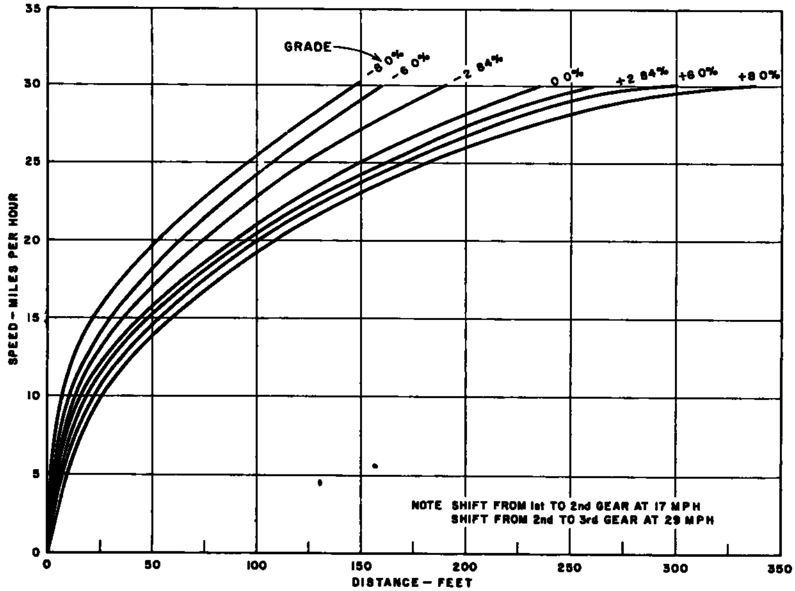

Figure 26. Distance required to accelerate with full throttle through all transmission gears from a standing start to 30 mph. on various upgrades and downgrades.

TABLE C

SUMMARY OF AVERAGE COMPOSITE PERFORMANCE OF TEST VEHICLE ON VARIOUS SECTIONS OF PENNSYLVANIA TURNPIKE BETWEEN CARLISLE INTERCHANGE AND NEW STANTON INTERCHANGE

Section	Length	Rise and fall	Average speed	Fuel consumption	Braking				Average engine torque	Average throttle opening
					Percent time		Max deceleration	Time factor		
					0-3 ft/sec²	over 3 ft/sec²				
	miles	ft /100 ft	mph.	mpg.	percent	percent	ft./sec²	sec/100 mi.	percent	percent
December 1951 & June 1952[1], Attempted Speed, 40 mph.										
1 - 2	6 88	1 3	39 8	18.8	99.8	0.2	8-10	19.6	27 6	14.3
2 - 3	6 69	2.0	39.1	17 6	100 0	0 0	0-3	0 0	28 5	15.9
3 - 4	4 31	1 4	41.1	18.4	100.0	0 0	0-3	0 0	27.5	15.6
4 - 5	7 04	2 2	39.0	18.1	100.0	0 0	0-3	0 0	26 6	15.0
5 - 6	3 63	2 3	41.0	18 0	99 9	0 1	4-7	9 6	27.0	16.2
6 - 7	19.21	1.3	39.2	18.6	99 9	0.1	8-10	7 0	26 4	15.3
7 - 8	6.80	2.5	40.5	17.9	100 0	0.0	4-7	2 2	27.9	15 3
8 - 9	28.25	1.2	40 4	19 3	100 0	0 0	0-3	0 0	26 9	14.7
9 - 10	6.31	1 4	41 3	18 9	100 0	0 0	0-3	0 0	26.5	14.8
10 - 11	9.32	1.4	38.7	18 8	100 0	0 0	0-3	0.0	26.1	0 0
11 - 12	18.19	1.6	40.3	19 3	99 9	0 1	11-13	3 6	26 7	13.8
12 - 13	6 17	0 9	40 7	18.8	100 0	0 0	0-3	0 0	28.0	14.3
13 - 14	2 11	1 9	39.4	17 0	100.0	0 0	0-3	0 0	29.8	12 1
14 - 15	11 01	1 3	41.1	18 7	100 0	0 0	0-3	0 0	27 0	14 3
15 - 16	12 79	0.8	41 1	19.3	100 0	0 0	4-7	1 2	27.1	14 5
Total(1-16)	148.71	1.4	40.2	18 8	100 0	0 0	11-13	2.7	27 0	14 7
December 1951 & June 1952[1], Attempted Speed, 50 mph										
1 - 2	6 88	1.3	49.1	16.0	99.8	0 2	4-7	14 5	36.3	19.3
2 - 3	6.69	2 0	49.0	15.5	99.9	0.1	4-7	7 5	35 5	19 5
3 - 4	4 31	1.4	50.3	16 1	99.9	0 1	4-7	3 5	33 6	19.0
4 - 5	7.04	2 2	46 1	15.9	99.9	0 1	4-7	9 2	32.6	16 7
5 - 6	3 63	2.3	49.1	15 6	99 6	0.4	4-7	27 5	34 3	19 3
6 - 7	19.21	1 3	48 0	16 8	99 9	0.1	8-10	5 2	32.8	17 8
7 - 8	6.80	2.5	49 3	16 4	99 8	0 2	4-7	12.5	35 7	20.9
8 - 9	28.25	1.2	50.0	17 1	99 8	0 2	8-10	15 4	33 4	17.8
9 - 10	6.31	1.4	50 7	16.8	99.8	0 2	8-10	5 5	34.2	18 6
10 - 11	9.32	1.4	46.4	16 9	99.9	0 1	4-7	3 8	32 8	16.5
11 - 12	18 19	1 6	48 7	17.5	99.9	0 1	4-7	3 6	32.1	16 8
12 - 13	6.17	0.9	48 8	16 7	100.0	0.0	0-3	0 0	33 4	17 6
13 - 14	2 11	1 9	45 0	15 7	99.8	0.2	4-7	16 6	33 1	16.5
14 - 15	11 01	1.3	51.1	17.0	100 0	0 0	0-3	0 0	32.8	17.7
15 - 16	12 79	0 8	50.7	17 4	100.0	0.0	4-7	1 2	34.0	17.3
Total(1-16)	148 71	1 4	49 0	16.8	99 0	0 1	8-10	7.6	33.5	17 8
June 1952, Attempted Speed, 60 mph.										
1 - 2	6 88	1.3	58 3	14 9	99 5	0.5	4-7	32 7	45.4	33.3
2 - 3	6.69	2.0	58.0	14.5	99.4	0.6	8-10	33.6	45.8	34.0
3 - 4	4 31	1.4	60.5	14.8	99 8	0 2	4-7	11.6	46.7	34 4
4 - 5	7 04	2.2	51 0	15.1	99.7	0.3	8-10	24 9	40.1	28.8
5 - 6	3 63	2.3	60 8	14.9	99.4	0 6	4-7	34 4	43 7	34 6
6 - 7	19.21	1 3	55 9	15 0	99.7	0 3	8-10	20 8	41 6	31 7
7 - 8	6 80	2.5	57.2	14 6	99.7	0, 3	8-10	18 4	43 0	32 1
8 - 9	28 25	1 2	59 9	15 4	99.5	0.5	11-13	20 4	42 9	32.3
9 - 10	6 31	1 4	60 0	15.1	99.5	0 5	4-7	31.7	43 6	33 5
10 - 11	9.32	1.4	49 4	15.7	99.6	0.4	4-7	26 8	37 7	26.5
11 - 12	18.19	1.6	56.2	15.5	99 9	0.1	4-7	6.9	41 4	29.8
12 - 13	6.17	0.9	55.7	14 8	100.0	0.0	0-3	0 0	42 0	29 7
13 - 14	2.11	1.9	44.6	14 4	99 4	0 6	8-10	47 4	37 0	23 4
14 - 15	11 01	1.3	60.1	14.9	99 8	0 2	4-7	11 4	44.8	32.4
15 - 16	12.79	0.8	60.8	15 2	99.9	0 1	4-7	3 9	45 2	32.7
Total(1-16)	148.71	1.4	57.1	15 1	99 7	0 3	11-13	18.5	42.6	31.3

[1] 1 test run in December 1951 and 2 test runs in June 1952

was determined to be approximately 24 seconds.

The relations in Figures 25 and 27 may be used to determine the average rate of fuel consumption for accelerating between two speeds. Considering full throttle acceleration on a plus-6-percent grade from 30 to 50 miles, the rate was 6.9 mpg. This was determined by dividing the distance in miles (Figure 27) by the fuel in gallons (Figure 25). The rate of 6.9 mpg. compares with one of 9.0 mpg., read from Figure 18 for a sustained speed of 50 mph. on an upgrade of 6 percent.

The instantaneous acceleration rates at various speeds are shown in Figure 29. The peak acceleration on the level occurs at a road speed of 35 mph., which approximates the speed of peak torque. The shape of the acceleration curve is similar to the shape of the maximum torque curve, and this should be the case, since acceleration is proportional to torque. The acceleration rates for the test vehicle are similar to those obtained by Normann (3) for the average of 53 vehicles. The following tabulation compares the instantaneous rates for various speeds:

Speed	Acceleration: Average vehicle (Normann)	Acceleration: Test vehicle
mph.	mph. per sec.	mph. per sec.
20	2.5	2.0
25	2.5	2.1
30	2.5	2.2
35	2.5	2.3
40	2.3	2.2
50	2.0	1.8
60	1.5	1.4
70	1.0	0.8

SPECIAL ANALYSES OF FUEL CONSUMPTION

Rise and Fall Relations

The relations between fuel consumption and rise and fall, shown in Figure 30 for attempted speeds of 30, 40, 50 and 60 mph., were derived from the rates of composite fuel consumption observed on the individual test sections of the New Jersey Turnpike, Maine Turnpike, Pennsylvania Turnpike (both sections), Shirley Highway, US 30 and US 11 in Pennsylvania, and US 40 in Maryland. The rates of fuel consumption for the test sections involved are given in the appropriate appendix. If the average speed for a test section was not within about 5 percent of the attempted speed, the rate of fuel consumption was not used in this analysis.

The average curves shown in Figure 30 for 30, 40, 50, and 60 mph. were based on 35, 79, 74, and 46 observations, respectively. There was a rather wide dispersion of the observed points about each of the curves. The standard errors of estimate, in miles per gallon, were 0.76 for 30 mph.; 0.79 for 40 mph.; 0.63 for 50 mph.; and 0.35 for 60 mph. Part of the wide scatter of data about the curves was undoubtedly due to the variations in the performance of test car during the period of the tests, shown previously in Figure 9. Another factor contributing to the large deviation was the inability to develop reliable correction factors for the varying accuracy of the fuel meter, shown in Figure 10.

The relations established between the rate of rise and fall and the rate of fuel consumption were similar in character to those shown in Figure 22, which were determined for sustained speed operation on short uniform grades. They provide a rather easy method for estimating the fuel consumption used on any section of road. The particular advantage is that any combination of grades can be considered at one time by determining the total rise and fall for the highway section. A disadvantage is the error that results, when the length of the steep grades is an appreciable portion of the total length being considered. This error results, because the composite effect of one foot of rise and fall, as shown in Figure 30, is appreciably greater for the rates of rise and fall above 6 feet per hundred feet. The rate of fuel consumption was also shown in Figure 22 to increase at a faster rate for grades over 6 percent.

Grade-Reduction Methods Compared

The savings in fuel consumption that result by reducing grades without a reduction in rise and fall and with a reduction in rise and fall are indicated in Table 3. They were computed using the example shown in Figure 31 and the rates of fuel consumption (gallons per mile) shown in Figure 23. In order to clarify the mechanics of the analysis, the problem of reducing an 8-percent to a 4-percent grade, will be described in detail for a speed of 30 mph.

Referring to Figure 31, if the reduction of the 8-percent grade is accomplished without a reduction in rise and fall, the saving in fuel would be the sum of the consumption on the 8-percent grade (AB) and from the 30-mph. curves in Figure 23. The saving in fuel is thus 0.00357 gal. The percentage of saving is 0.00357 gal. divided by 0.002340 gal., or 15.2 percent.

If the reduction in the 8-percent grade is made by reducing rise and fall, the saving in gallons would be the consumption on the 8-percent grade (AB) minus the con-

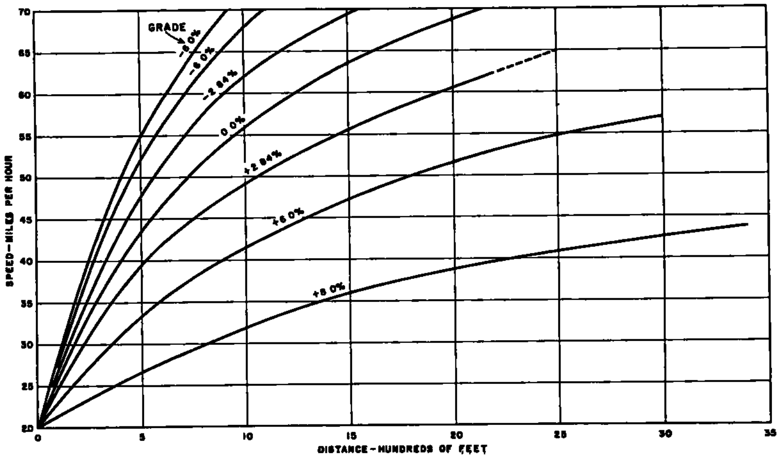

Figure 27. Distance required to accelerate with full throttle in third gear from 20 mph. to higher speeds on various upgrades and downgrades.

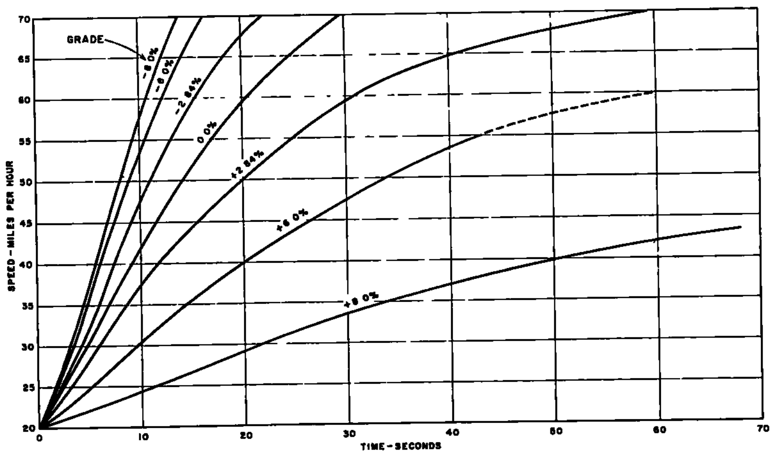

Figure 28. Time required to accelerate with full throttle in third gear from 20 mph. to higher speeds on various upgrades and downgrades.

the level section (BD), minus the consumption on the 4-percent grade (AD). The fuel consumed was 0.001983 gallon on AD (200 feet), 0.001491 gallon on AB (100 feet) and 0.000849 gallon on BD (100 feet). These values of consumption were determined by multiplying the length of the respective section in miles by the rate of consumption read for the specified grade sumption on the 4-percent grade (AH). The consumption on AB (100 feet) was previously determined to be 0.001491 gallon. Using the rate of consumption shown in Figure 23 for the 4-percent grade, the fuel consumed on AH (100 feet) was determined to be 0.000992 gal. A saving of 0.000499 gal. (33.4 percent) resulted.

It is seen in Table 3, that Method 2 al-

TABLE D

SUMMARY OF AVERAGE COMPOSITE PERFORMANCE OF TEST VEHICLE ON VARIOUS SECTIONS OF US 11 AND 30 BETWEEN CARLISLE AND GREENSBURG, PENNSYLVANIA

Date of Tests - June 1952

Section	Length	Rise and fall	Average speed	Fuel consumption	Braking				Average engine torque
					Percent time		Max. deceleration	Time factor	
					0-3 ft/sec²	over 3 ft/sec²			
	miles	ft./100 ft.	mph.	mpg.	percent	percent	ft./sec²	sec/100 mi.	percent
				Attempted Speed, 30 mph.					
A - B	19.8	2.2	31.1	19.3	99.8	0.2	8-10	26.6	26.9
B - C	4.0	6 3	30.8	14.0	97.9	2.1	4-7	223.9	37.2
C - D	2.4	6.4	31 4	15.3	99.6	0.4	4-7	41.5	35 8
D - E	9 6	5.1	31.2	16.4	98.8	1.2	11-13	127.5	32.3
E - G	5.7	3.9	32.0	18.3	100 0	0 0	4-7	4 4	29 5
G - H	4.2	3.1	31.0	18.1	100.0	0 0	0-3	0 0	26.9
H - I	5.0	6 2	31.6	15.0	98.5	1 5	8-10	161.3	36 5
I - J	27.0	2.5	30.2	18.1	99.6	0.4	11-13	47 3	28.8
J - K	4.3	5.0	30.8	15.8	99 2	0 8	4-7	87.4	35.0
K - L	1.0	4.8	32.8	17.8	100 0	0 0	0-3	0.0	33.6
L - M	1.9	5.1	31.1	15.4	99 6	0 4	4-7	39.9	33.6
M - N	3.0	7.3	31.7	13.6	98.9	1 1	4-7	41.4	40.4
N - O	4.1	4 1	31 9	17.2	98.9	1.1	4-7	123 2	31.0
O - P	1.4	7.9	30.0	13.6	97.6	2.4	4-7	262.2	42.2
P - Q	3.4	4.9	31 7	16.5	99 2	0.8	4-7	88.2	34.1
Q - R	3.6	6.6	29 3	13 8	98.0	2.0	11-13	235 5	38.5
R - S	3 9	7 0	31.9	13.7	97.8	2 2	8-10	232.0	39.9
S - T	30.3	1.7	29.4	19 5	99 4	0 6	11-13	71.8	27.5
T - U	14.8	1.4	31.0	19 7	100 0	0.0	0-3	0.0	27 6
Total (A-U)	149.4	3.3	30 6	17 6	99.4	0 6	11-13	70.5	30.2
				Attempted Speed, 40 mph					
A - B	19.8	2 2	39.3	18.0	99.7	0 3	11-13	36.2	29.4
B - C	4.0	6 3	38.9	14.2	97 9	2.1	4-7	182.8	39.9
C - D	2.4	6 4	40.3	14.6	99.6	0.4	4-7	33 2	38.3
D - E	9.6	5.1	39.0	16.3	99 2	0 8	8-10	69.2	34 3
E - G	5.7	3.9	40.7	17.3	99.9	0 1	4-7	8 7	31.5
G - H	4.2	3.1	39.8	16.9	100 0	0.0	0-3	0.0	29.1
H - I	5.0	6.2	38 1	14.6	96.8	3.2	4-7	295.4	39 5
I - J	27 0	2.5	37.4	17.5	99.5	0.5	11-13	46.3	30 6
J - K	4.3	5.0	38 6	15.1	99.2	0 8	8-10	73.4	38.2
K - L	1 0	4 8	41 3	15.3	100.0	0.0	0-3	0 0	37.6
L - M	1.9	5.1	39 4	14.4	99.8	0.2	4-7	18 6	36.7
M - N	3.0	7.3	37.0	13.6	96.3	3.7	4-7	342.7	42.3
N - O	4 1	4 1	39.5	16 3	96.6	3.4	11-13	304.2	34.9
O - P	1.4	7 9	36 9	13.4	95.1	4 9	8-10	454 5	44.4
P - Q	3.4	4 9	39.7	15 7	97.9	2.1	8-10	186.8	38.7
Q - R	3.6	6.6	32 7	14 6	96.0	4 0	8-10	429.4	38.5
R - S	3.9	7.0	39 0	13 4	97.0	3 0	4-7	261 6	43.3
S - T	30.3	1 7	35 6	17.6	99 2	0.8	11-13	82 1	29.5
T - U	14.8	1.4	40.3	17 6	99.9	0.1	4-7	3.4	29 9
Total (A-U)	149.4	3 3	38.0	16.6	99.0	1 0	11-13	93.5	32.6
				Attempted Speed, 50 mph.					
A - B	19.8	2.2	43 0	17.2	99.2	0.8	11-13	67.3	33.6
B - C	4 0	6 3	43.7	13.8	93.8	6.2	8-10	481.3	45 7
C - D	2.4	6.4	49.1	15.4	99 3	0 7	4-7	47.7	43 4
D - E	9 6	5 1	44.5	15.3	98.3	1.7	8-10	126.4	38.8
E - G	5.7	3.9	49.3	16.0	99.4	0.6	4-7	43.7	36.2
G - H	4.2	3 1	48.7	15.3	99.6	0 4	8-10	32.1	35 3
H - I	5.0	6.2	41.5	14.6	94.6	5.4	8-10	450 6	43.4
I - J	27.0	2.5	42.2	16.3	98.5	1 5	14-16	124.7	34.9
J - K	4.3	5.0	41.3	14.0	96.1	3.9	8-10	322.8	41.3
K - L	1.0	4.8	49 8	13 6	99.1	0.9	4-7	62.5	41.7
L - M	1.9	5.1	43.4	12.7	98.3	1 7	8-10	133.0	44 6
M - N	3.0	7.3	42.7	13.8	90.7	9.3	8-10	756.6	48.0
N - O	4.1	4.1	45 5	14.9	92.5	7.5	11-13	533.3	39.3
O - P	1.4	7.9	38.5	13.1	89.6	10.4	11-13	919.6	49.3
P - Q	3.4	4.9	45.9	14.3	97.0	3.0	8-10	230.9	41.0
Q - R	3.6	6.6	33.9	13 2	91.8	8.2	14-16	826.9	44.1
R - S	3.9	7.0	43.2	13.8	92.7	7.3	8-10	576.0	48 7
S - T	30.3	1 7	39.0	16.2	98 2	1.8	11-13	156.9	33 3
T - U	14.8	1.4	48.2	16.1	99.4	0.6	8-10	40.5	34.2
Total (A-U)	149.4	3.3	42.7	15.6	97.6	2 4	14-16	196.8	36.3

ways results in the largest saving. A reduction in grade by Method 1 appears to result in appreciable savings for grades in excess of 6 percent. However, grades of 6 percent or under must be reduced by Method 2, if any substantial saving is to gained by reducing grades of 6-, 4-, or 3-percent by Method 1, or by reducing grades of 4- and 3-percent by either method. It can be readily seen that reducing grades, per se, may not result in appreciable savings in fuel consumption.

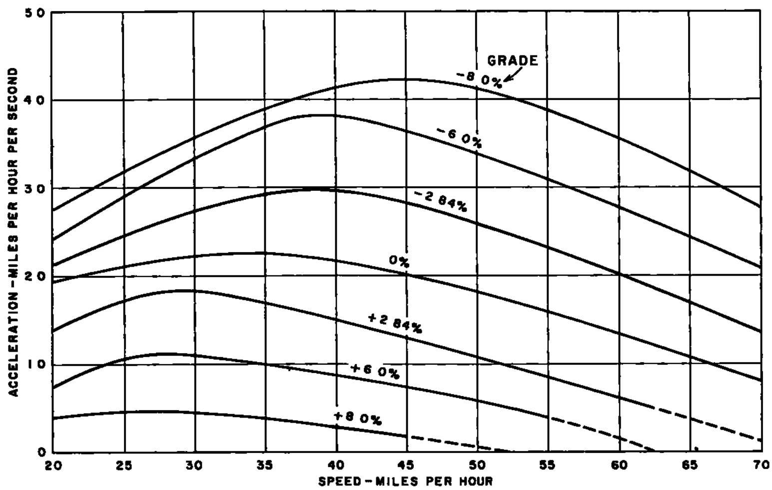

Figure 29. Average instantaneous acceleration rates at various speeds operating in third gear on various upgrades and downgrades.

TABLE 3

SAVINGS IN FUEL CONSUMPTION RESULTING BY TWO METHODS OF GRADE REDUCTION

Grade reduction	Percentage of saving for sustained speeds of -							
	30 mph.		40 mph.		50 mph.		60 mph.	
	I[a]	II[b]	I	II	I	II	I	II
Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
8 to 6	16.7	25.7	12.7	20.2	7.5	11.3	-	-
8 to 4	15.2	33.4	10.9	26.0	6.0	17.6	-	-
8 to 3	13.1	36.5	8 7	28.0	4.9	19.6	-	-
8 to 2	9.8	39.0	6.6	30 4	3 7	21.6	-	-
6 to 4	3.0	10 5	1.7	7.4	2 0	7.0	3.1	8.7
6 to 3	3.3	14.5	1 4	9.9	1.8	9.2	3.7	11.9
6 to 2	2.7	17.9	1.5	12 8	1.5	10 4	2.6	13.7
4 to 3	0.9	4 5	0.1	2.7	0.3	2.4	1 3	3.5
4 to 2	1 1	8 3	0 6	5.9	0.5	4.8	0.9	5.5
3 to 2	0 4	3.9	0.5	3.3	0.3	2 4	0.0	2.0

[a] Method I - No reduction in rise and fall
[b] Method II - Reduction in rise and fall

be realized. It is emphasized that the savings shown in Table 3 are based on the fuel characteristics of one passenger car, and that they could be materially different for other vehicles.

The differences between the two methods of grade reduction are clearly shown in Figure 32. The savings are those shown in Table 3 for a sustained speed of 50 mph. Except for the reduction of an 8-percent to a 6-percent grade, Method 1 is shown to be much inferior to Method 2. Little is

Fuel Computation by Various Methods

The 21.0-mile section of US 40 between Frederick and Hagerstown, Maryland, was selected for checking various methods that can be used to measure and compute fuel consumption, because the lengths of steep grades constituted a sizable portion of the total length. This section of highway had a rate of rise and fall of 3.7, the highest of any test route studied. About 29 percent

TABLE E

AVERAGE COMPOSITE PERFORMANCE OF TEST VEHICLE IN TOWNS ON US 11 AND US 30 IN PENNSYLVANIA

Town	Pop. 1950 census	Dates of test	Length	Rise and fall	Average speed	Fuel con-sumption
			miles	ft. /100 ft.	mph.	mpg.
Ligonier	2,160	July 52	1.19	2.1	24.2	21.4
Bedford	3,521	June 52	1.41	2.2	20.7	17.7
Everett	2,297	June 52	1.29	1.0	22.0	18.6
McConnellsburg	1,126	June 52	0.96	2.8	30.4	18.0
Chambersburg	17,212	June 52	2.36	1.3	17.0	17.9
Shippensburg	5,722	June 52	1.87	1.2	19.4	18.0
Total	-	-	9.08	1.6	20.6	18.4

TABLE F

AVERAGE COMPOSITE PERFORMANCE OF TEST VEHICLE ON SECTIONS OF PENNSYLVANIA US 11 AND US 30 WITH LARGE TOWNS, EXCLUDING THE TIME AND FUEL USED IN THE TOWNS

Section [1]	Length	Rise and fall	Average speed	Fuel consumption
	miles	ft. /100 ft	mph.	mpg
Attempted Speed, 30 mph.				
A - B	18 6	2.2	31 6	19.2
I - J	24.3	2 6	31 6	18 2
Q - R	2 6	8.0	29.6	12 8
S - T	26.1	1.8	32.8	19 8
Total (A-U)	140 3	3.4	31.6	17 5
Attempted Speed, 40 mph				
A - B	18 6	2 2	40 9	17.8
I - J	24.3	2.6	40.8	17 5
Q - R	2 6	8 0	33.8	13 8
S - T	26 1	1 8	42.3	17.5
Total (A-U)	140 3	3 4	40.3	16 5
Attempted Speed, 50 mph.				
A - B	18 6	2.2	45.3	17.0
I - J	24 3	2.6	47 4	16.1
Q - R	2.6	8 0	35.6	12.2
S - T	26 1	1 8	48 0	16.0
Total (A-U)	140 3	3 4	46.0	15 5

[1] Towns excluded

A-B	Ligonier
I -J	Bedford and Everett
Q-R	McConnellsburg
S-T	Chambersburg and Shippensburg

TABLE G

AVERAGE COMPOSITE PERFORMANCE OF TEST VEHICLE ON VARIOUS SECTIONS OF MAINE TURNPIKE BETWEEN KITTERY AND PORTLAND

Date of Tests, August 1952

Section	Length	Rise and fall	Average speed	Fuel consumption
	miles	ft. /100 ft	mph.	mpg.
Attempted Speed, 40 mph.				
1 - 2	17.2	1 3	39.7	19 7
2 - 3	6.2	1 5	40.1	19.2
3 - 4	5 9	0 9	40.0	19.1
4 - 5	3.4	0 8	39.8	19.0
5 - 6	9 1	1 1	39.6	18.9
Total (1-6)	41 8	1 2	39.8	19.3
Attempted Speed, 50 mph.				
1 - 2	17 2	1 3	49.1	17 0
2 - 3	6.2	1 5	49.4	16 0
3 - 4	5.9	0 9	49 3	16 4
4 - 5	3 4	0.8	49.2	16 3
5 - 6	9.1	1 1	48.4	16.4
Total (1-6)	41 8	1 2	49.0	16.5
Attempted Speed, 60 mph				
1 - 2	17.2	1.3	58 8	14 9
2 - 3	6.2	1.5	59 3	14 8
3 - 4	5 9	0.9	59.3	15.0
4 - 5	3 4	0 8	59.0	14 2
5 - 6	9.1	1.1	58 2	14 9
Total (1-6)	41.8	1 2	58.8	14 9

TABLE H

AVERAGE COMPOSITE PERFORMANCE OF TEST VEHICLE ON VARIOUS SECTIONS OF US 1 BETWEEN KITTERY AND PORTLAND, MAINE, USING "AVERAGE" TEST METHOD

Date of Tests, August 1952

Section	Length	Rise and fall	Average speed	Gasoline consumption
	miles	ft /100 ft.	mph.	mpg
		Weekday		
A - B	17.9	1.5	37.0	17.6
B - C	5.2	1.2	34.7	17.0
C - D	7.4	1 1	40 2	17.9
D - E	1.9	1 6	21.3	19.8
E - F	11.4	1.3	38.5	18.4
Total (A-F)	43 8	1.3	36.4	17 9
		Weekend		
A - B	17.9	1.5	35.6	18 0
B - C	5.2	1.2	31.2	17 2
C - D	7.4	1.1	40.4	17.3
D - E	1.9	1 6	19.1	18.2
E - F	11.4	1 3	38 5	17.9
Total (A-F)	43.8	1 3	35.1	17.7

of its length was on grades of 5 percent or more and about 15 percent on grades of 7 percent or greater.

The fuel consumption in gallons, determined by the various methods for an attempted speed of 50 mph., is shown in Table 4. Fuel was measured with a burette on one test, and with the fuelmeter on three tests. The fuel consumption was computed by two methods that use individual grades and by two methods that use the rate of rise and fall, which has been called the composite or average grade by other investigators.

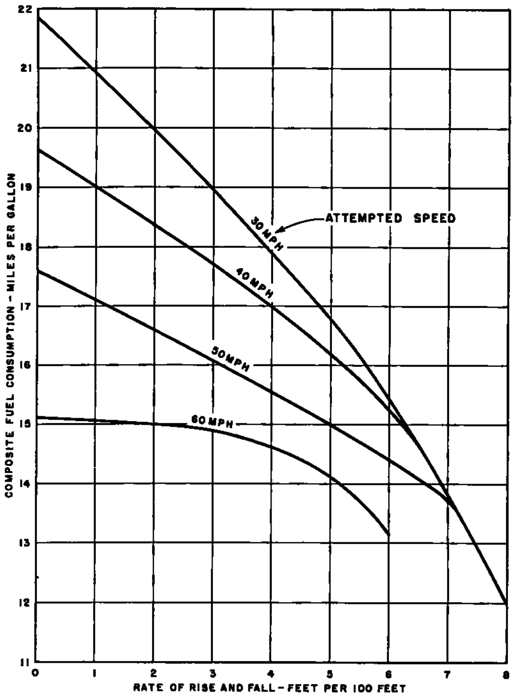

Figure 30. Relation between fuel consumption and the rate of rise and fall.

TABLE 4

SUMMARY OF FUEL CONSUMPTION BETWEEN FREDERICK AND HAGERSTOWN, MARYLAND, MEASURED AND COMPUTED BY VARIOUS METHODS FOR ATTEMPTED SUSTAINED SPEED OF 50 MPH.

Section	Section length	Rise and fall rate	Burette Aug. 1952	Fuel meter measurement July 1951	Aug. 1952	Sept. 1952	Avg	Individual grade method	Rise and fall method: Rise and fall relation	Individual Grade relation	Grade classification method
	miles	ft./100ft.	gal	gal.	gal.	gal.	gal.	gal.	gal.	gal.	
A - B	3.5	3.8	-	.200	-	.220	210	.224	223	.219	.223
B - C	1.8	4 5	-	.106	-	.117	.112	.119	.118	.115	.118
C - D	4 1	3.8	-	.231	-	.252	.242	264	.262	.256	.266
D - E	2.4	5.7	-	.149	-	160	.154	.167	.164	160	.165
E - F	2.6	5.2	-	.156	-	.167	.161	.173	174	.170	.172
F - G	6.6	2.2	-	368	-	.390	.379	.399	.400	.398	.399
Total (A-G)	21.0	3 7	1 280	1 210	1.318	1.306	1.278	1 346	[a]1.333	[a]1 310	1.343
Percent variation from burette measurement - Aug. 1952			0.0	-5.5	+3.0	+2.0	-0.2	+5.2	+4.9	+2.3	+5.0

[a] Based on rate of rise and fall for total section. (Not a summation of values for intermediate sections.)

The values in the column headed "individual grade method" are the summation of the fuel consumptions computed for each individual grade in the section. This method required 198 computations using

TABLE I

AVERAGE COMPOSITE PERFORMANCE OF TEST VEHICLE ON VARIOUS SECTIONS OF US 40 (NEW) BETWEEN FREDERICK AND HAGERSTOWN, MARYLAND

Date of Tests, July 1951

Section	Length	Rise and fall	Average speed	Fuel consumption	Braking: Percent Time 0-3 ft/sec²	Braking: Percent Time over 3 ft/sec²	Braking: Max deceleration	Braking: Time factor	Average engine torque	Average throttle opening
	miles	ft /100 ft	mph	mpg	percent	percent	ft/sec²	sec/100 mi	percent	percent
Attempted Speed, 30 mph										
A - B	3 5	3 8	32 4	18 6	100 0	0 0	0-3	0 0	28 0	23 2
B - C	1 8	4 5	32 8	18 0	100 0	0 0	0-3	0 0	28 1	23 6
C - D	4 1	3 8	32 1	19 1	100 0	0 0	0-3	0 0	26 6	22 5
D - E	2 4	5 7	33 0	15 8	100 0	0 0	0-3	0 0	32 3	24 8
E - F	2 6	5 2	31 5	17 7	100 0	0 0	0-3	0 0	30 1	24 6
F - G	6 6	2 2	32 2	19 9	100 0	0 0	4-7	3 8	22 6	22 1
Total (A-G)	21 0	3 7	32 3	18 5	100 0	0 0	4-7	1 2	26 8	23 1
Attempted Speed, 40 mph										
A - B	3 5	3 8	41 7	17 3	100 0	0 0	0-3	0 0	30 7	26 4
B - C	1 8	4 5	41 1	17 7	100 0	0 0	0-3	0 0	30 6	26 1
C - D	4 1	3 8	41 1	17 5	100 0	0 0	0-3	0 0	29 5	26 4
D - E	2 4	5 7	40 5	15 1	100 0	0 0	0-3	0 0	35 6	27 5
E - F	2 6	5 2	40 8	17 7	100 0	0 0	0-3	0 0	31 0	28 5
F - G	6 6	2 2	40 7	18 6	100 0	0 0	0-3	0 0	28 1	24 7
Total (A-G)	21 0	3 7	40 9	17 5	100 0	0 0	0-3	0 0	30 3	26 2
Attempted Speed, 50 mph										
A - B	3 5	3 8	49 9	16 5	100 0	0 0	0-3	0 0	36 1	28 9
B - C	1 8	4 5	49 6	15 9	100 0	0 0	0-3	0 0	34 5	30 5
C - D	4 1	3 8	49 5	16 5	99 8	0 2	14-16	12 4	33 0	29 9
D - E	2 4	5 7	49 3	15 0	98 6	1 4	27-29	105 9	38 8	31 3
E - F	2 6	5 2	48 7	15 7	100 0	0 0	0-3	0 0	35 3	29 7
F - G	6 6	2 2	49 4	16 9	99 6	0 4	4-7	26 6	31 7	28 2
Total (A-G)	21 0	3 7	49 4	16 2	99 7	0 3	27-29	22 8	34 2	29 4
Attempted Speed, 60 mph										
A - B	3 5	3 8	51 9	16 2	99 8	0 2	4-7	14 3	39 2	32 7
B - C	1 8	4 5	52 8	14 7	99 6	0 4	4-7	27 8	44 1	34 1
C - D	4 1	3 8	54 2	15 2	99 3	0 7	8-10	43 4	39 7	33 5
D - E	2 4	5 7	51 3	12 7	99 1	0 9	4-7	63 6	41 5	34 2
E - F	2 6	5 2	52 5	14 0	99 7	0 3	4-7	19 2	45 6	32 4
F - G	6 6	2 2	55 1	15 2	99 7	0 3	4-7	19 0	39 8	35 2
Total (A-G)	21 0	3 7	53 4	14 8	99 6	0 4	8-10	28 7	41 0	33 9

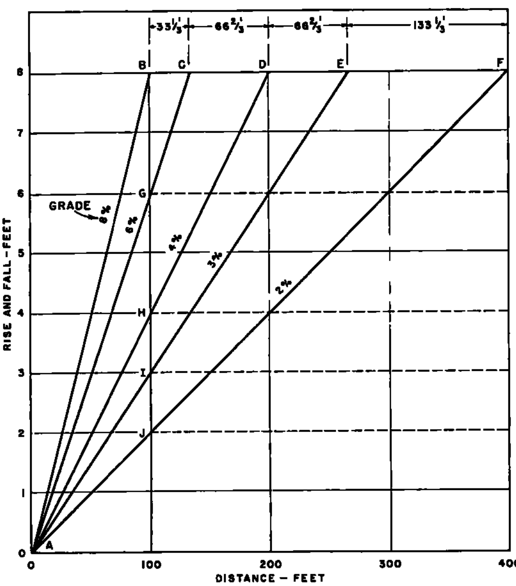

Figure 31. Example for determining savings in fuel consumption by two typical methods of grade reduction.

TABLE J

AVERAGE COMPOSITE PERFORMANCE OF TEST VEHICLE ON VARIOUS SECTIONS OF US 40 (NEW) BETWEEN FREDERICK AND HAGERSTOWN, MARYLAND

Date of Tests, September 1952

Section	Length	Rise and fall	Average speed	Fuel consumption	Braking: Percent time 0-3	Braking: Percent time over 3	Braking: Max deceleration	Braking: Time factor
	miles	ft /100 ft	mph	mpg	ft sec²	ft /sec²	ft sec²	sec /100 mi
Attempted Speed, 40 mph								
A - B	3 5	3 8	40 1	17 2	100 0	0 0	0-3	0 0
B - C	1 8	4 5	39 3	17 4	99 7	0 3	4-7	27 8
C - D	4 1	3 8	39 4	17 7	100 0	0 0	0-3	0 0
D - E	2 4	5 7	39 6	15 8	99 7	0 3	4-7	21 2
E - F	2 6	5 2	39 1	17 6	100 0	0 0	0-3	0 0
F - G	6 6	2 2	39 7	18 3	99 9	0 1	4-7	7 6
Total (A-G)	21 0	3 7	39 6	17 5	99 9	0 1	4-7	7 2
Attempted Speed, 50 mph								
A - B	3 5	3 8	43 0	15 9	99 5	0 5	4-7	42 9
B - C	1 8	4 5	48 5	15 4	98 5	1 5	8-10	111 1
C - D	4 1	3 8	48 9	16 0	99 8	0 2	4-7	12 4
D - E	2 4	5 7	48 7	14 7	99 7	0 3	4-7	21 2
E - F	2 6	5 2	48 6	15 6	100 0	0 0	0-3	0 0
F - G	6 6	2 2	49 0	16 8	100 0	0 0	0-3	0 0
Total (A-G)	21 0	3 7	47 7	16 0	99 7	0 3	8-10	21 6
Attempted Speed, 60 mph								
A - B	3 5	3 8	53 8	15 1	99 8	0 2	4-7	14 3
B - C	1 8	4 5	56 1	14 4	97 4	2 6	4-7	166 7
C - D	4 0	3 8	54 6	14 6	98 1	1 9	8-10	124 1
D - E	2 4	5 7	56 8	13 4	96 7	3 3	8-10	211 9
E - F	2 6	5 2	52 5	14 1	99 7	0 3	4-7	19 2
F - G	6 6	2 2	54 6	15 2	99 9	0 1	4-7	38 1
Total (A-G)	21 0	3 7	54 6	14 6	99 8	1 2	8-10	79 1

TABLE K

AVERAGE COMPOSITE PERFORMANCE OF TEST VEHICLE ON VARIOUS SECTIONS OF ALTERNATE US 40 (OLD) BETWEEN FREDERICK AND HAGERSTOWN, MARYLAND

Date of Tests, July 1951

Section	Length	Rise and fall	Average speed	Gasoline consump-	Braking: Percentage of time 0-3 ft./sec.²	Braking: Percentage of time over 0-3 ft./sec.²	Braking: Max decel.	Braking: Time factor	Average engine torque	Average throttle opening
	miles	ft./100 ft	mph	mpg			ft./sec.²	sec./100 mi.	percent	percent
1 - 2	2.4	4.3	34.5	16 1	98 8	1.2	8-10	128.8	34.7	20 8
2 - 3	0 7	6.3	25.9	11.6	94 1	5 9	8-10	820 9	37.0	22.0
3 - 4	5.1	4.3	38 2	17 0	99.6	0.4	8-10	44.1	29.3	20.5
4 - 5	2.1	4.8	32.6	15 4	99.6	0.4	4-7	48.1	28.2	18.9
5 - 6	1.3	6 4	32.1	14 5	98.5	1.5	4-7	173.1	39.7	20.8
6 - 7	3 2	3.1	38.6	17.9	99.2	0 8	4-7	7.9	27 0	20.2
7 - 8	5.4	3 4	40 5	18.0	100.0	–	0-3	–	27.1	22.2
8 - 9	1.3	3 3	26 3	15.8	98 0	2 0	4-7	270.8	28.1	19.2
Total (1-9)	21 5	4.1	35.9	16 6	99.2	0.8	8-10	82.4	29.9	20.7

TABLE L

AVERAGE COMPOSITE PERFORMANCE OF TEST VEHICLE ON VARIOUS ROUTES BETWEEN WASHINGTON, D. C., AND ANNANDALE, VIRGINIA

Date of Tests, July 1951

Period of day	Section	Length	Rise and fall	Average speed	Fuel consumption	Braking: Percent time 0-3 ft/sec²	Braking: Percent time over 3 ft/sec²	Braking: Max. deceleration	Braking: Time factor	Average engine torque	Average throttle opening
		miles	ft./100 ft.	mph	mpg	percent	percent	ft./sec²	sec/100 mi	percent	percent
	Highway Bridge to Annandale via Columbia Pike										
Off-peak	A-2B	2 3	1.8	33 7	18.0	99 6	0.4	4-7	44.5	27.2	21.5
	2B-3B	3.0	2 8	30.9	17 5	96 9	3.1	8-10	444 1	28.8	18.0
	3B-4	4.1	2.4	34 5	17 9	98.5	1 5	8-10	147.4	29.0	22.1
	Total (A-4)	9 4	2.4	33.1	17 8	98 2	1.8	8-10	219.1	28.5	20.4
Peak	A-2B	2.3	1.8	28 7	17 6	97.7	2 3	4-7	289.5	27 5	18.6
	2B-3B	3 0	2.8	19 7	14 0	96.8	3 2	8-10	592 1	27.3	15.6
	3B-4	4 1	2 4	34 5	15.6	98.5	1 5	8-10	122.8	34.1	28 4
	Total (A-4)	9 4	2.4	26 6	15.4	97.5	2.5	8-10	315 3	29.3	20.1
	Highway Bridge to Annandale via Shirley Highway										
Off-peak	A-2A	4 3	1 8	43 7	18 1	99 8	0.2	4-7	11.7	30 2	27.2
	2A-3A	2 5	2 2	50.0	18.0	99.4	0 6	4-7	39.2	42.0	34.9
	3A-4	3.5	1 6	40 6	17 2	99 1	0.9	4-7	71 3	33.0	27 0
	Total (A-4)	10 3	1.8	43.9	17 7	99.5	0 5	4-7	38.7	33.8	28.8
Peak	A-2A	4 3	1.8	36 0	16 7	99 2	0.8	4-7	81 6	27.5	22 9
	2A-3A	2.5	2.2	48.7	15.0	98 9	1.1	8-10	78.4	40.2	32.5
	3A-4	3 5	1.6	40 1	17.0	97.7	2.3	8-10	199.7	31.2	26.6
	Total (A-4)	10.3	1 8	40 0	16.4	98.6	1.4	8-10	120 8	31.4	26.2
	Memorial Bridge to Annandale via Columbia Pike										
Off-peak	B-2B	2 6	1.8	33 3	17 5	99.1	0.9	8-10	97 5	28.1	21.5
	2B-3B	3.0	2 8	31.4	17.5	98 7	1 3	11-13	148.0	29 3	21.6
	3B-4	4.1	2 4	37.5	17 2	98 1	1.9	11-13	184 3	29.5	23.9
	Total (B-4)	9 7	2.4	34 3	17 4	98.6	1 4	11-13	149.9	29.1	22.5
Peak	B-2B	2.6	1 8	24.5	16 1	99 2	0.8	8-10	117.0	28.2	18.2
	2B-3B	3 0	2 8	21 4	14 2	96 3	3.7	8-10	625.0	28.5	16.8
	3B-4	4 1	2 4	34 5	15.9	96.8	3 2	11-13	331.7	33.1	23.9
	Total (B-4)	9 7	2.4	26 5	15.4	97 3	2.7	11-13	366.9	30.0	19.5
	Memorial Bridge to Annandale via Shirley Highway										
Off-peak	B-2A	4 5	1.7	46 2	18 0	99.2	0 8	8-10	67.0	33.1	29 2
	2A-3A	2.5	2 2	50 9	18.0	100.0	0.0	0-3	0 0	40.1	34.6
	3A-4	3.5	1.6	41 0	17.2	97.1	2 9	8-10	256 8	34.2	27.1
	Total (B-4)	10 5	1.8	45 3	17.7	98 6	1.4	8-10	114.0	35.1	29.6
Peak	B-2A	4 5	1.7	37.5	16 9	99 3	0 7	4-7	67.0	28.8	24.0
	2A-3A	2 5	2.2	48.3	15 0	100.0	0 0	0-3	0.0	34.7	31.5
	3A-4	3.5	1.6	41 4	17.0	100.0	0 0	0-3	0.0	28.5	26.2
	Total (B-4)	10.5	1 8	41 0	16.4	99.7	0.3	4-7	28.5	29.9	26.2

TABLE M

AVERAGE SPEED AND FUEL CONSUMPTION OF TEST VEHICLE BETWEEN WASHINGTON, D C , (HIGHWAY BRIDGE) AND WOODBRIDGE, VIRGINIA VIA SHIRLEY HIGHWAY

Date of Tests, March 1954

Section	Length	Rise and fall	Attempted Speeds							
			Posted speed limits [a]		50 mph. [b]		40 mph.		30 mph	
			Speed	Fuel	Speed	Fuel	Speed	Fuel	Speed	Fuel
	miles	ft. /100 ft	mph.	mpg.	mph.	mpg	mph.	mpg	mph.	mpg
A - B	1 95	1.6	39.1	18.4	41.1	18 7	39.4	18.9	—	—
B - C	2.43	1.8	50.1	18 5	49 1	18.7	41 4	20.4	—	—
C - D	0 87	1.6	54.0	18 6	48 2	17 6	40 2	20 0	30 0	20 3
D - E	1 69	2.6	55.8	16 2	52.2	18 4	41.8	19 8	31.1	21 2
E - F	1 62	1.5	53.8	16.7	47.4	18.0	40 1	19.6	30 4	20 8
F - G	1 91	0 8	51.9	16.4	50 0	18.3	40.4	19 7	30.4	21.0
G - H	2 73	0.7	54.8	17.6	50 5	17.5	40.8	19.8	31 7	22 0
H - I	3.15	1.0	55.7	17.5	51 0	18.5	41.9	20.3	32 0	22 1
I - J	2.09	0.5	49 7	16 2	46.7	16.9	38.6	18.5	28 9	20 0
Total (A-J)	18.44	1.3	50 9	17.2	48.5	18 1	40.6	19.7	—	—
(C-J)	14.06	1.1	53.2	16.8	49 5	17 9	40 6	19 6	30 8	21 1

[a] 40 mph. for section A-B, 50 mph. for section B-C and 55 mph. for remaining sections.

[b] Except A-B where posted limit of 40 mph. was obeyed.

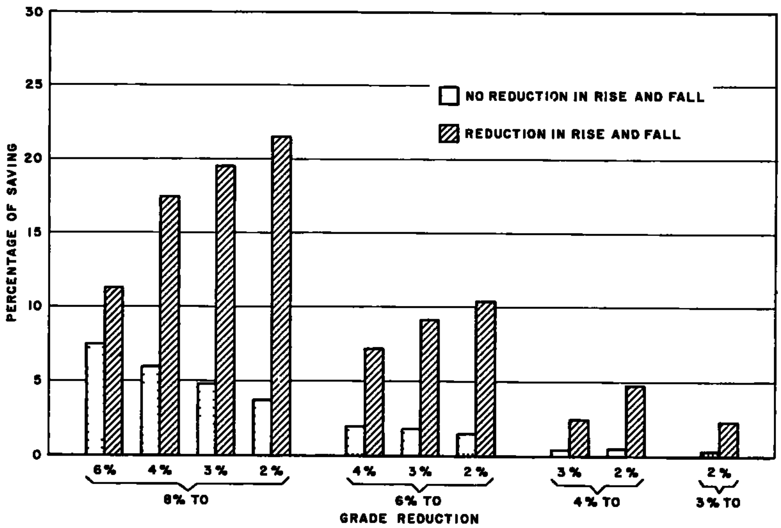

Figure 32. Savings in fuel consumption resulting by two methods of grade production for a sustained speed of 50 mph.

the rates of fuel consumption shown in Figure 23.

The grade-classification method is a simplified version of the method just discussed. The individual grades were grouped in four classes of grade; 0 to 3 percent, 3 to 5 percent, 5 to 7 percent, and 7 to 9 percent. The total length in each class was then multiplied by the rate of fuel consumption in gallons per mile obtained from Figure 23 for the midpoint of the particular grade class. This method is not quite so laborious as the previous one and gave almost identical results.

The rise-and-fall method required only one computation for a given section. The first column under this method contains values that were computed with the fuel consumption rates shown in Figure 30 for various rates of rise and fall. The values

TABLE N

FUEL CONSUMPTION AND SPEED OF OPERATION ON SECTION OF COLUMBIA PIKE BEFORE AND AFTER INSTALLATION OF TRAFFIC ACTUATED CONTROL EQUIPMENT

Period	Speed			Fuel consumption		
	In-bound	Out-bound	Avg.	In-bound	Out-bound	Avg.
	mph.	mph.	mph.	mpg	mpg.	mpg.
			Before, April 1952			
A M. off-peak	25.4	26 8	26.1	16.7	15.8	16.3
A M peak	20 0	23 8	21.8	13 8	13 7	13 8
P M peak	22.2	19.8	20.9	13.0	12.5	12 8
Avg. peak	21 1	21.8	21 4	13 4	13.1	13 3
			After, August 1952			
A M. off-peak	26 1	25.0	25.5	15 7	15 7	15.7
P M. off-peak	23.9	24.7	24 3	13 4	13 5	13.4
Avg. off-peak	25.0	24.8	24 9	14.6	14 6	14 6
A.M peak	20.9	22.9	21 9	14.2	12 7	13.4
P.M peak	22 3	20.0	21 1	15.0	15.4	15.2
Avg. peak	21 6	21.4	21.5	14 6	14.0	14 2

in the second column headed "individual-grade relation" were based on the rates for individual grades shown in Figure 23.

The fuel measured with the burette was used as a common base for comparative purposes. The percentage of variations from the burette measurement shown in Table 4, indicates that all methods gave results which were within reasonable limits of error. The much simpler rise-and-fall method appears to be as good as, or better than, the two methods which require a solution for each individual grade.

The results obtained with the fuel meter also did not vary appreciably from those measured with the burette.

Analysis of Flow on an Urban Thorofare

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Reading Road has been one of the most-heavily travelled thoroughfares in Ohio, carrying US 25 and US 42, and heavy local traffic. In 1950, a series of major changes in the traffic control was inaugurated, which culminated in the installation of a completely remodeled traffic signal system in the Winter of 1952-53.

This paper presents a description of the changes which were made in the traffic control and a study of the effects of these changes in terms of traffic volumes, capacity, accident records, delays and operating speeds, and on certain operating characteristics of motor vehicles using Reading Road.

The traffic signal system of this 3.85-mile section was remodeled to include two signal faces in each direction on Reading Road, plus pedestrian signals across nearly every crosswalk at signals. Signals were added to one intersection in the group to bring the total number signalized to 24. Signal spacing varies from 250 feet to 1,950 feet, and there is a wide range of spacing between these figures. Many innovations were used to get a reasonable degree of progressive movement, notwithstanding such uneven spacing. The most-outstanding of these was the use of semi-traffic-actuated control units, with a background cycle, at intersections interfering most with progression.

In addition to studies of traffic volumes, capacities, accident records, and speeds and delays, a new method was used in studying the effects of traffic on vehicle-operating characteristics before and after the changes in the traffic signals. These studies were made simultaneously with the conventional speed and delay studies, using a test car equipped with statistical instruments developed by the Highway Research Board Committee on Motor Vehicle Characteristics. These instruments measured vehicle speed, fuel consumption, braking, engine torque, and throttle opening on the car during the 54 test runs made after the traffic signal modernization was completed.

The studies showed that the revisions in traffic control had raised the practical capacity at three critical intersections by an average of 13 percent and that traffic volumes on the road had increased, by 1954, between 10 and 15 percent since 1952.

The studies also showed that, despite the increase in traffic volumes, the average trip during the 1954 studies consumed about 7.5 percent less time than during the 1952 studies and that the accident records showed a 21 percent decrease in accident occurrence at signalized intersections in 1953 as compared with 1952.

Savings have therefore accrued to motorists using the road in time saved, in lower vehicle operating costs, and in reduced accident costs, amounting to at least $140,000 per year, as compared with an installation cost for the system of approximately $85,000.

The studies also indicated that statistical testing equipment of this type should be extremely valuable in the analysis of the effects of traffic flow conditions on vehicle-operating characteristics.

● THE YEAR 1950 was the turning point for traffic signals in Cincinnati. Citizens approved a bond issue of $900,000 for new signals and modernization of existing signals. This, of course, was not adequate money to complete the project, but it was enough to give Cincinnati a taste of standard traffic signalization designed for maximum intersectional capacity and safety. The result of improvements so far has been to show people what can be done to assist traffic and thus bring them into a more cooperative mood toward further signal projects. Of course, the program has been criticized, but this criticism has decreased as greater public understanding was realized.

Traffic signals, themselves, are certainly no cureall for traffic accidents. It has been shown time and again that a traffic signal may increase the number of accidents but usually reduces their severity. Most of you will agree, however, that when traffic signals are properly used they can be one of the most-valuable and most-effective devices for expediting and safeguarding traffic on our antiquated city streets.

From the safety standpoint, traffic signals are only as effective as their ability to be seen. Their effectiveness in carrying volumes of traffic depends upon their timing. Other factors are involved but will not be evaluated in this discussion.

THE PROBLEM

Reading Road was singled out as a prime project early in the program of traffic signal modernization in Cincinnati. The section of Reading Road studied in this paper is 3.85 miles in length (Figure 1) and involved the modernizing of 23 existing signalized intersections and the addition of one newly signalized cross street.

Reading Road is essentially 50 feet wide throughout the section studied and originally had street-car rails in both directions, but street cars have not operated on them for several years. The street passes through apartment developments and strip businesses for its entire length. It carries US 25 and US 42 and State Route 4 joins Reading Road at Paddock Road, thus adding to the amount of through traffic.

The original installation of signals took place over a period of years and was influenced by such factors as neighborhood pressure, as well as traffic considerations; hence, the spacings between signals are irregular. Even without some of the less-essential signals, the spacing would be far from ideal between some of the important cross streets that actually warrant signal installations.

A street with a curb-to-curb width of 50 feet and parking on both sides cannot effectively carry four lanes of moving traffic. Reading Road had peak-hour parking restrictions for inbound traffic in the morning and outbound traffic in the evening, but it will be shown later how this did not fulfill the traffic demand of the street. Use of an offset centerline and

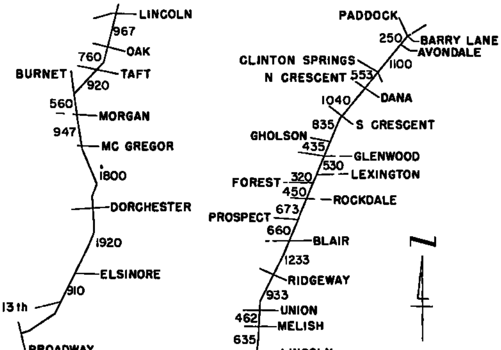


Figure 1. Vicinity map, showing signalized intersections and area studied.

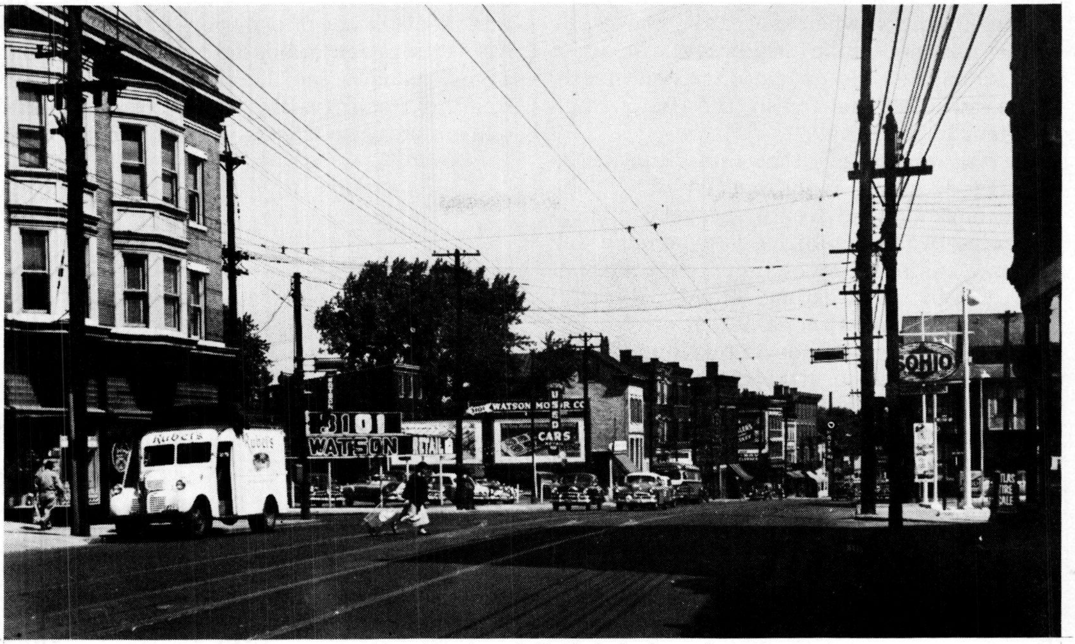


Figure 2. Reading Road and Melish before improvements.

five lanes will also be shown as the new street laning.

The original Reading Road signal system consisted of one three-light signal head mounted horizontally at the far right of each traffic approach (Figures 2 and 3). These were installed during the late 1920's and 1930's; in general, their physical condition was poor, and in many cases their visibility left much to be desired.

The old system operated on a 46-second cycle and did a fair job of moving light traffic, but it would become very congested under heavy peak hour loads, or even at

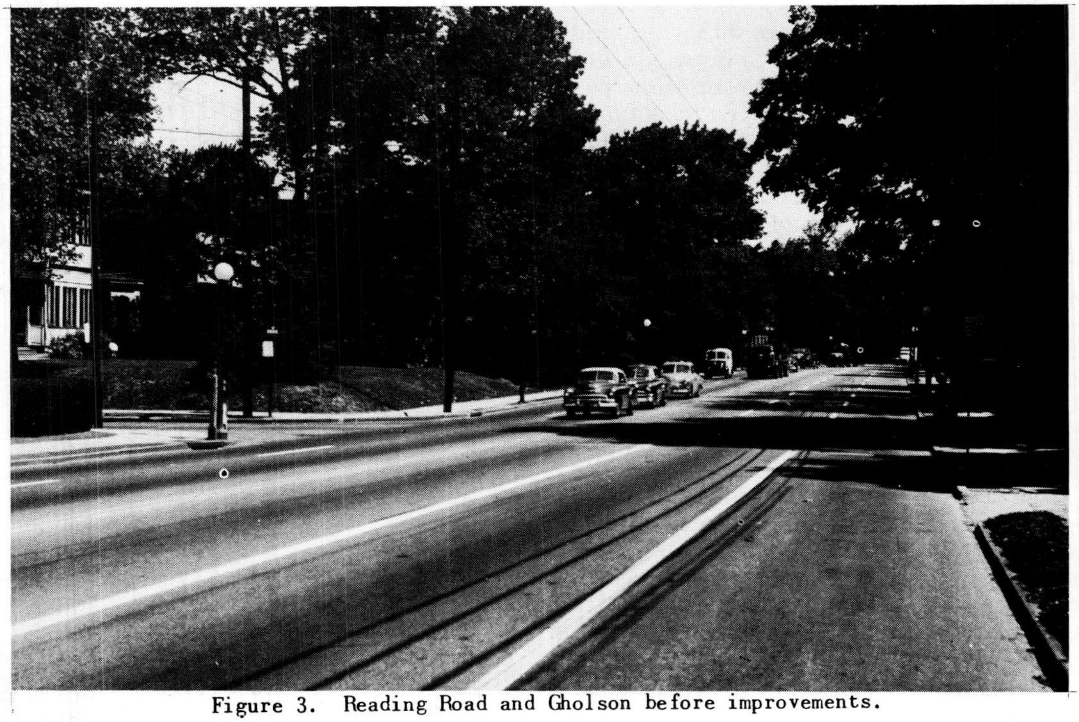


Figure 3. Reading Road and Gholson before improvements.

off-peak hours when several trucks or buses reached close headways. Most of the signalized intersections continually appeared near the top in the list of high accident locations.

It was mandatory that this situation be corrected, since increased vehicle registration demanded greater street capacity. Widening was prohibitively expensive due to heavy business developments on most of this length of Reading Road. Parallel routes are almost nonexistent or too far away. The only way for improvements for the present was to make the best possible use of our existing 50-foot roadway. Ultimately a new expressway will relieve this thorofare, but completion date is not earlier than 1957.

SIGNAL PROJECT DEVELOPMENT

The first step in a traffic-signal-modernization project is to gather data on the street under consideration. The geographical proportions of Reading Road are seen in Figure 1. Distance between signalized intersections vary from 250 feet to 1,920 feet. The overall length of the project is 18,906 feet. A time-space chart for the entire project was laid out at a 200-foot scale on a cross section tracing paper. Many prints from this tracing were used to lay out combinations of signal progression. These prints were 30 inches wide and 10 feet long. The large drawings were used to insure as accurate timing as possible. The method employed in obtaining the proper offsets was the conventional method of using pins and thread to arrive at the proper speed and traffic band widths.

Due to the profusion of signalized intersections, many of them minor cross streets, it became necessary to use all major cross streets on Reading Road in laying out the basic "progression chart." Best results were obtained with a 60-second cycle. When this was completed, the minor cross streets were worked into the basic chart as semi-traffic-actuated signals with a background cycle controlled from the resynchronizing line just as fixed-time controllers. This is accomplished by the use of synchrolizers at each of the eight semiactuated units.

Figure 4 shows a small section of the original progression chart. Union and Lincoln avenues were on the basic chart and Melish Avenue, already a signalized intersection but of a minor nature, had to have its green adjusted to a position that would cause the least interference to Reading Road traffic. As long as no actuation occurs, this section operates as a simple ½ cycle offset system. When an actuation does occur, it can be seen that traffic flow in one direction is not interfered with, but the other direction has its band width reduced considerably. If the actuations were to continue indefinitely during peak traffic, considerable congestion would accumulate. A thorough study of traffic counts and characteristics at this and comparable locations disclosed that there would be enough cycles with no

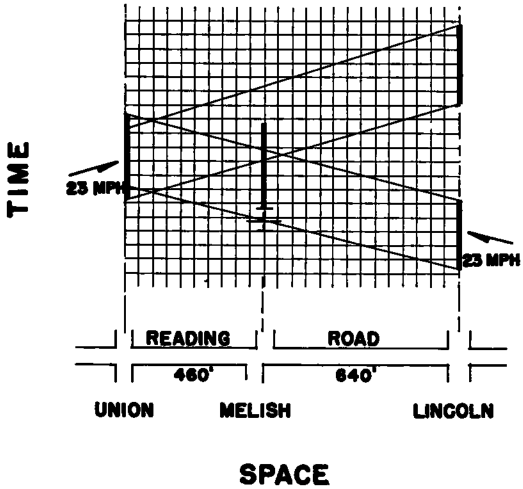


Figure 4. Portion of Reading Road progression chart, Lincoln to Union.

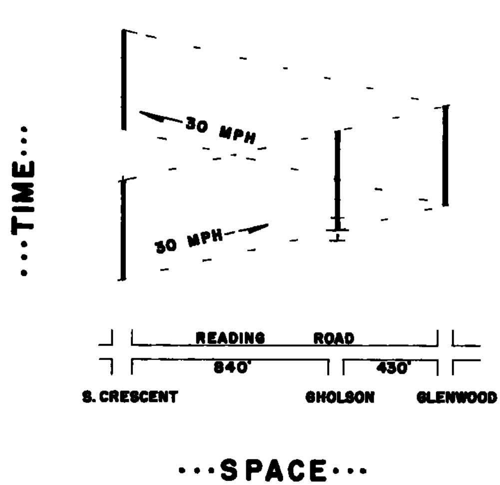


Figure 5. Portion of Reading Road progression chart, Glenwood to South Crescent.

actuation that the congestion could be kept to a minimum.

Figure 5 shows another small section of the progression chart. The conditions here were essentially the same as shown in the previous figure, except that Gholson Avenue intersects Reading Road as a T intersection.

Reading Road at this point is 50 feet wide, curb to curb. An offset centerline allows two southbound lanes, two northbound lanes, and a parking lane which becomes a northbound lane from 4 p. m. to 6 p. m. No parking is allowed in the southbound curb lane at any time.

accommodate Gholson Avenue traffic, an unusual combination of signal control was devised.

The signal at Gholson Avenue is semiactuated with the background cycle and timed so it will progress southbound traffic on Reading Road. The northbound traffic which normally would be interrupted is accommodated in a through lane (Figure 6) which is separated physically from traffic emerging from Gholson Avenue by a half round concrete divider curb. In this way northbound traffic can move at all times, except when it is interrupted by a pedestrian actuation (which stops all Reading

Figure 6. Reading and Gholson after improvements.

Road traffic). Pedestrian movement is light at this intersection so northbound interruptions are few.

Gholson Avenue is 430 feet north of Glenwood Avenue and 840 feet south of South Crescent Avenue. This again is not conducive to proper progression in both directions with a cycle length that will carry the vehicle volumes. A speed of 30 mph. can be maintained in both directions between Glenwood Avenue and South Crescent Avenue if the signal at Gholson Avenue was removed. The signal could not be removed; so to cause a minimum of interference to Reading Road traffic and still

Traffic counts were taken on all the cross streets involved and along Reading Road at key locations. From these counts it was determined what the cross-street timing should be and also used to discover what streets could be considered minor enough to receive the semiactuated treatment as previously described.

Analysis of traffic volumes on Reading

Road disclosed that traffic peaks in both directions at about the same time, both morning and afternoon, thus making directional preferential offsets of no value (Figure 7). Offsets that would carry heavy traffic in both directions were mandatory.

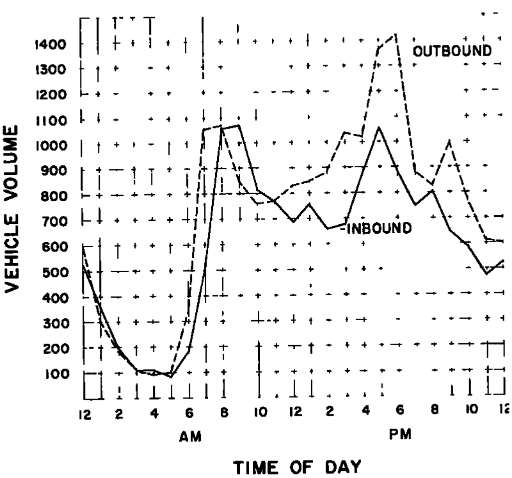


Figure 7. Reading Road traffic volumes, typical hourly distribution.

Signal splits at the fixed-time intersections were calculated by the conventional method but special consideration had to be given the timing of the semiactuated controllers. The conventional isolated signal-timing method no longer applied. Operation with a background cycle meant that the controller, after the expiration of the main street green, was no longer waiting to immediately turn to the side street green upon actuation. This means that the detector placement is no longer a function of the dial setting and speed. To insure a short minimum side street green, it became necessary to place the detectors within 40 to 60 feet of the stop line, thus making it possible to have a green as short as nine seconds. The detector is placed in a position that will allow to pass only the cars ahead of it that can theoretically and normally pass through the minimum green setting. Any additional vehicles will be behind the detector and will receive additional green extensions as they pass over the detector. This will clear any unusually large group of vehicles on the side street with a minimum of delay.

If the detectors were placed the conventional way, the minimum side-street green would, of necessity, be quite long, due to a possible prolonged waiting period until the background cycle would release the signal to permit side street movement. In other words, it would be possible to fill up the long space between detector and the stop line; thus making a long minimum green necessary. The maximum side street green is determined by traffic counts.

Early in the program the decision was made to use double signal indications (Figure 8) on all state and federal routes. One indication is about 5 feet from the right curb and the other is just left of the centerline. From the visibility standpoint this is ideal; a driver can always have one signal head or the other in view at all times. Also, there is little possibility that both signal heads will be lost in a maze of neon signs. A paper (1) on signal visibility has shown that overhead signals in contrast to curb mounted signals can be placed both closer to a motorist's normal line of sight and at an almost constant angle, regardless of street width.

Double signal indications are a tremendous safety factor in case of burnouts. It is seldom that there is a double burnout, leaving an approach to a signalized intersection dark.

In addition to the signal indications for traffic, each of the signalized intersections has at least one crosswalk with "Walk" and "Wait" indications. In areas of heavier pedestrian activity all crosswalks are controlled by pedestrian signals. The pedestrian signals are timed to give a clearance period to the pedestrian so Reading Road will be clear as the platoons of vehicles arrive at the intersection.

The entire project involving the 24 signalized intersections plus the interconnecting control cable was written in contract forms and bids asked. Low bid was $72,100. This amounted to just over $3,000 per intersection for all new signal equipment and the labor for installing it. This price also included the labor of removing the old equipment. Parking signs, paint lines, etc., accounted for approximately $13,000 additional to complete the project for a total of $85,000.

Construction was begun at Thirteenth Street on the south end of the project and proceeded to the north, intersection by intersection. The project was completed, with a minimum of delay to traffic, about three months after it was started.

Capacity studies showed that the revision in traffic control had raised the practical capacity (2) of Reading Road at three critical intersections on Reading Road by an average of 13 percent. At many intersections the practical capacity was raised as much as 30 percent. A typical intersection is Reading Road and Elsinore Place, where the practical capacity increase was 17.7 percent. Reading Road, here, had a practical capacity of 1,580 vehicles per hour, and after the improvement the practical capacity was increased to 1,860 vehicles per hour.

RESULTS AND COMPARISONS

General Considerations

In attempting to evaluate a traffic engineering improvement, a basis for comparison must first be established. Using, as a guide, the definition of traffic engineering, criteria were set up, and studies of conditions before and after the improvements on Reading Road were made as follows: (1) roadway capacity and traffic volumes actually carried; (2) safety, as reflected in accident records; (3) convenience, as reflected in freedom from delays, running speeds, and travel time; and (4) economy, reflected in three major economic factors of traffic operations: (a) costs due to accidents, (b) vehicle-operating costs, (c) monetary costs of delays and lost time in traffic.

In this study of traffic conditions, a relatively new and still largely experimental method was used in measuring certain aspects of both convenience and economy. This method involved the use of statistical testing equipment developed by the Highway Research Board's Committee on Vehicle Characteristics.

These studies had as objectives, first, to determine the effects of the modernized traffic signal system installed on Reading Road, and second, to investigate the use of the statistical testing equipment in studying the effects of traffic flow on vehicle-operating characteristics.

Capacity and Traffic Volumes

As stated earlier, the revised lane lin-

Figure 8. Reading and Melish after improvement.

ing and modernized signal system increased the capacity at the signalized intersections on Reading Road by amounts up to 30 percent.

Meanwhile, traffic volumes on Reading Road, as throughout Cincinnati and all over the country, have increased tremendously in the years since World War II. The traffic survey reports of 1948 and 1952, published by the Ohio Highway Planning Survey, showed that the average daily vehicle mileage travelled on Reading Road, between Broadway and Paddock Road, increased from 77,450 in 1948 to 85,700 in 1952. Traffic-volume studies by the Division of Traffic Engineering of the City of Cincinnati in 1954 showed the average daily vehicle mileage to exceed 105,000 vehicle-miles per day. Table 1 shows the actual

TABLE 1

TRAFFIC VOLUMES ON READING ROAD

Section	Traffic Volumes 1948	1952	1954
Broadway to Elsinore	27,190	28,580	31,585
Elsinore to Taft	19,590	21,380	25,652
Taft to Rockdale	17,300	19,420	25,439
Rockdale to Paddock	20,440	23,340	30,061

traffic volumes reported in various sections of Reading Road by the three studies. Table 2 shows the mileage figures for the same sections.

TABLE 2

VEHICLE-MILEAGE ON READING ROAD

Length	Section	Vehicle-Mileage 1948	1952	1954
0.46 mi.	Broadway to Elsinore	12,500	13,150	14,550
1.18 mi.	Elsinore to Taft	23,100	25,200	30,250
1.20 mi.	Taft to Rockdale	20,800	23,300	30,600
1.03 mi.	Rockdale to Paddock	21,050	24,050	31,000

These studies indicate that traffic volumes on Reading Road increased between 10 and 15 percent between 1952 and 1954, and that the average daily traffic volume on most of the section covered in this paper in 1954 was approximately 27,000 vehicles. There are some short portions which carry greater volumes than this due to east-west cross traffic having to jog over Reading Road.

Accident Records

The total number of accidents reported in this section decreased 3.5 percent (from 749 in 1952 to 723 in 1953). However, accidents at locations other than at signalized intersections increased from 301 in 1952 to 369 in 1953, while the accidents at signalized intersections decreased from 448 in 1952 to 354 in 1953, a decrease of 21.0 percent.

The record of personal injuries and fatal accidents showed a similar change. In 1952, there were 96 injury accidents and four fatal accidents (including two at signalized intersections), while in 1953, there were 94 injury accidents and only one fatal accident, that one being midblock. Here again, injury and fatal accidents at other than signalized intersections increased from 36 to 44, while injury and fatal accidents at signalized intersections decreased from 64 to 51, or 20.3 percent.

There is no readily apparent reason why the accidents at locations other than signalized intersections on Reading Road should have increased at a rate considerably greater than the city-wide increase for such accidents. However, it is of interest to note that the percentage of accidents occurring at the signalized intersections on Reading Road decreased from 59.8 percent of the total number of accidents in 1952, to 49.0 percent in 1953.

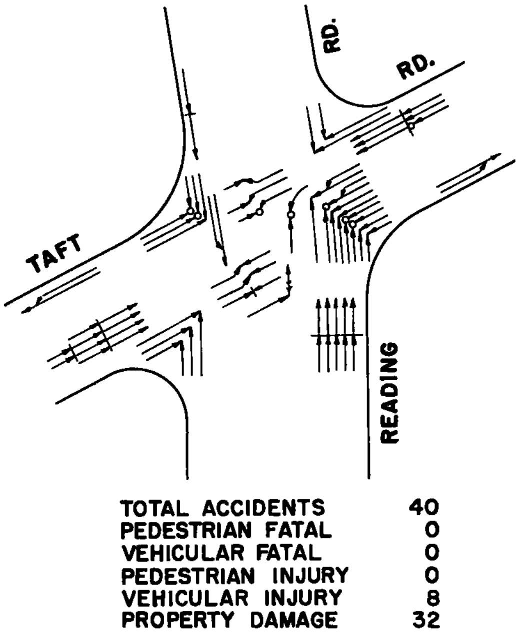
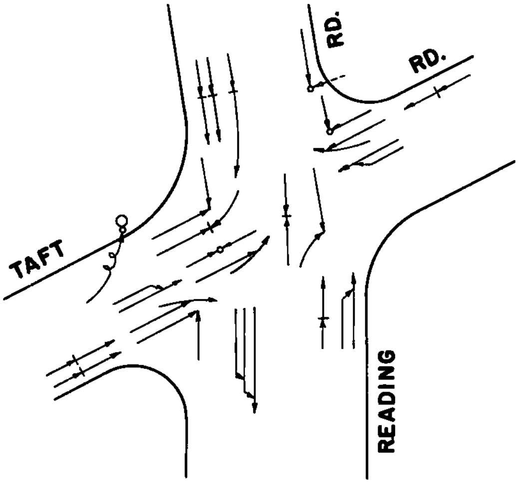


Figure 9. Reading and Taft collision diagram before signal improvements.

One surprising development was the fact that although the total number of reported accidents at signalized intersections decreased, the number of pedestrian accidents increased from 17 to 23. This increase occurred in spite of the fact that the revised signal system included pedestrian signals for at least one crosswalk across Reading Road at every signalized intersection andat all crosswalks in areas of greater pedestrian activity. Analysis of the individual accidents showed a considerable increase in pedestrian signal violations in 1953 as compared with 1952. However, records for the first 10 months of 1954 showed only one accident caused by a pedestrian violation and the pedestrian accident record appears to show a downward trend, so the difficulty may have been largely due to unfamiliarity of the pedestrians with the new system.

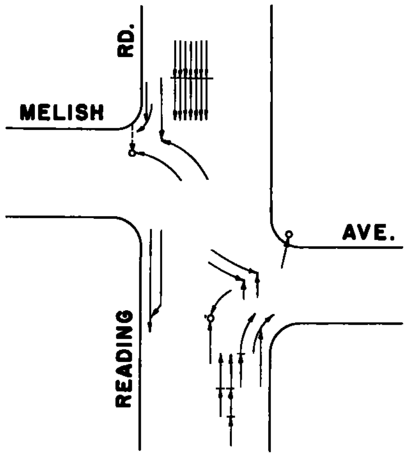


TOTAL ACCIDENTS	23
PEDESTRIAN FATAL	0
VEHICULAR FATAL	0
PEDESTRIAN INJURY	1
VEHICULAR INJURY	3
PROPERTY DAMAGE	19

Figure 10. Reading and Taft collision diagram after signal improvements.

Many of the signalized intersections on Reading Road showed slight changes in their accident records. A few of the locations, however, showed major improvements. Two examples of intersections which showed notable decreases in reported accidents from 1952 to 1953 were: Reading and Wm. H. Taft, from 40 to 23 accidents; and Reading and Melish, from 19 to 6 accidents. Figures 9, 10, 11, and 12 show collision diagrams of these two intersections for 1952 and 1953, or before and after the signal improvements.

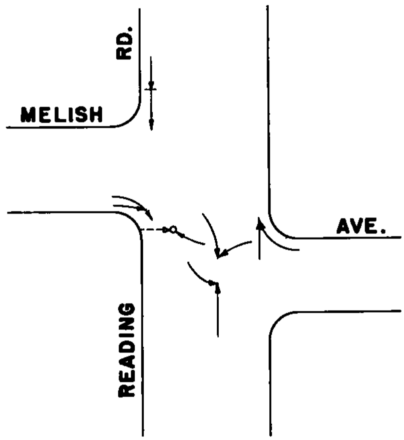
Only two intersections showed major increases in accident occurrence. These were Reading, Dorchester, and Florence,



TOTAL ACCIDENTS	19
PEDESTRIAN FATAL	0
VEHICULAR FATAL	0
PEDESTRIAN INJURY	1
VEHICULAR INJURY	1
PROPERTY DAMAGE	17

Figure 11. Reading and Melish collision diagram before signal improvements.

where accidents increased from 20 to 36, and Reading and Gholson, where accidents increased from 9 to 30. Detailed accident analyses have been made of these two locations to determine the causes for the increases, and corrective measures have been taken. Records for the first 10 months of 1954 indicate that these measures have been beneficial, as the inter-



TOTAL ACCIDENTS	6
PEDESTRIAN FATAL	0
VEHICULAR FATAL	0
PEDESTRIAN INJURY	1
VEHICULAR INJURY	0
PROPERTY DAMAGE	5

Figure 12. Reading and Melish collision diagram after signal improvements.

sections showed 16 and 17 accidents reported, respectively, for the 10-month period. The accident records also indicate that the improvement shown at most of the other signalized intersections from 1952 to 1953 has continued during 1954.

Characteristics of Traffic Flow and Vehicle Operation

Moving-car speed-and-delay studies were made on Reading Road in October, 1952, immediately prior to the installation of the revised signal system, and again in April, 1954, approximately a year after the completion of the revised system. The latter studies also included studies of vehicle operating characteristics which were made with the statistical testing equipment developed by the HRB Committee on Vehicle Characteristics.

The statistical testing equipment was described in detail by Carmichael and Haley (3). These instruments measure speed, fuel consumption, deceleration, engine torque, and throttle opening, and record their data in the form of numbers on banks of electrical counters, which are mounted inside the car. All the instruments except the fuel meter, which registers each 0.001 gallon of gasoline consumed, register once each second. On each unit the total number of counts recorded on all the dials in that unit represents the number of seconds the equipment is in operation. As a check, the equipment also includes a separate counter dial which records the total number of seconds of operation.

Speed-and-delay data on Reading Road obtained by means of the so-called average-car method, in which the driver attempts to maintain a speed typical, in his opinion, of the traffic flow, were used in these studies. We have found a rigid application of the so-called floating-car method, in which the driver attempts to follow the general rule of passing as many vehicles as pass the test car, impractical on congested urban thoroughfares. The computed results of the average-car speed-and-delay studies include average travel time, average operating (or overall) speed, average running speed, and causes, locations, and average durations of delays incurred by the test car.

In combining the speed-and-delay studies and the vehicle-operating-characteristics studies on Reading Road, the two types of tests were made simultaneously. The statistical testing equipment was started at the starting point of the speed-and-delay test, and turned off at the end point of the test. The timer on the testing equipment then gave an excellent check on the elapsed time recorded on the speed-and-delay test, and the data from the two types of tests represented exactly the same traffic and operating conditions.

In both the before and the after studies, the tests were divided into three time groups for a typical day; the morning peak hours, from 7 a.m. to 9 a.m.; the off-peak hours, from 9 a.m. to 4 p.m.; and the evening peak hours from 4 p.m. to 6 p.m. At least eight test runs were made in each group and in each direction. These hourly groupings were based on the peak-hour parking restrictions on Reading Road, and approximately 65 percent of the average daily traffic on Reading Road occurs during this 11-hour period. On Figure 7, showing a typical hourly distribution of traffic volumes at one point on Reading Road, the shaded area indicates the portion of the average daily traffic represented by the 11-hour period.

The studies showed that the average operating time or travel time on Reading Road had decreased and the average operating speed (or overall speed) had increased in both directions and in each time grouping in the 1954 studies as compared with the 1952 studies. The increases in average operating speeds ranged from 0.4 mph. to 2.1 mph. and the decreases in average operating times ranged from 7 seconds to 68 seconds.

The average time saving in 1954 during the 11-hour period covered by the tests was 53.1 seconds per trip between Broadway and Paddock, or about 7.5 percent from the 1952 studies. This represented an average increase in operating speed from 19.5 mph. in the 1952 studies, to 21.1 mph. in the 1954 studies. These average figures are obtained by weighing the average operating times of the tests from each time group, according to the traffic volumes which they represent.

Aside from the definite, but unmeasurable, cost of congestion or lost time in traffic in driver fatigue, nerve strain, and inconvenience, there has been considerable discussion in recent years as to the monetary value of the lost time. It is not the purpose of this paper to enter this discussion, but rather to use a single conservative value of purposes of comparative study on Reading Road. W. R. Bellis (4) stated that assigned values for time lost have ranged from 1 to 4 cents per vehicle-minute, with 2 cents per vehicle-minute, or $1.20 per vehicle-hour, being a probable reasonable figure. A. J. Bone (5) used a value of $1 per hour in his travel-time studies in Boston in 1951. It appears, therefore, that a figure of $1.20 per hour, or 2 cents per minute, would be a conservative figure, and a simple one to use in this study.

Considering an average daily traffic volume of 27,000 vehicles, the traffic volumes represented by the Reading Road studies amounted to approximately 17,500 vehicles daily in 1954. On the basis of a time saving of 53.1 seconds per trip, the studies showed a saving of 257.64 vehicle-hours per day, or 94,035 vehicle-hours per year. At $1.20 per hour, this amounts to a monetary saving of $309.17 per day, or approximately $113,000 per year. These savings represent only those realized by traffic during the 11-hour period represented by these studies. Although no attempt was made to evaluate them, it is highly probable that savings have also been realized by the motorists using Reading Road during other hours of the day.

All of the data obtained from the statistical testing equipment is in the form of numbers, and therefore, can be plotted on

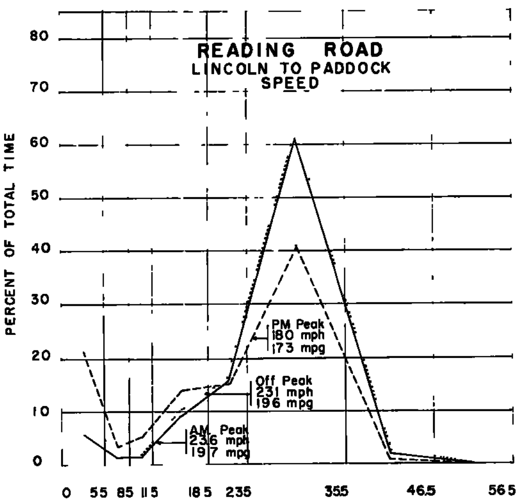


Figure 13. Time versus speed for Reading Road, Lincoln to Paddock.

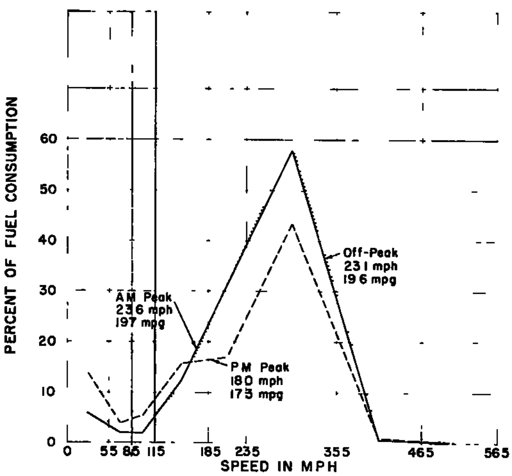


Figure 14. Fuel consumption versus speed for Reading Road, Lincoln to Paddock.

charts or graphs. Figure 13 shows typical curves obtained from the speed meter, and Figure 14 shows typical curves obtained from the fuel meter. The speed meter registers not only the amount of fuel consumed, but the amount used in each speed range. It would seem apparent that on both these charts, the most-satisfactory and most-economical driving conditions are represented by curves showing high peaks in the speed ranges in which vehicles normally cruise under urban conditions, and which show low values in the lower speed ranges which represent reduced speeds and actual delays. This is shown clearly in these two charts; the curves for the evening peak hour tests, in which much-lower operating speeds and fuel economy were recorded, show much less time and fuel consumed at cruising speeds, and much-more time and fuel consumed at very low speeds, than do the other test periods.

Figure 15 shows typical curves of deceleration characteristics, showing the percentage of time spent in various ranges of deceleration rates. In general, it is probably true that the most-satisfactory and most-economical operating conditions would be represented by the curve in the lowest position on the chart, although higher operating speeds may result in the occasional occurrence of higher rates of deceleration.

Figures 16 and 17 show typical charts of the devices measuring engine torque and throttle opening. Although these curves

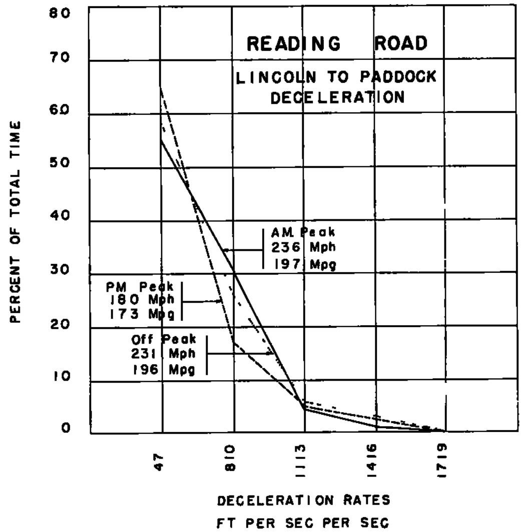


Figure 15. Time versus deceleration for Reading Road, Lincoln to Paddock.

do vary with operating conditions, as yet no definite relationships have been established.

One of the major purposes of this study was to determine whether there are any relationships between the traffic-flow characteristics of a given roadway, as shown by the speed-and-delay studies, and the operating characteristics of a vehicle using the roadway. The results of the studies show that several general relationships do exist.

One of the most-significant of these relationships is that of fuel consumption to

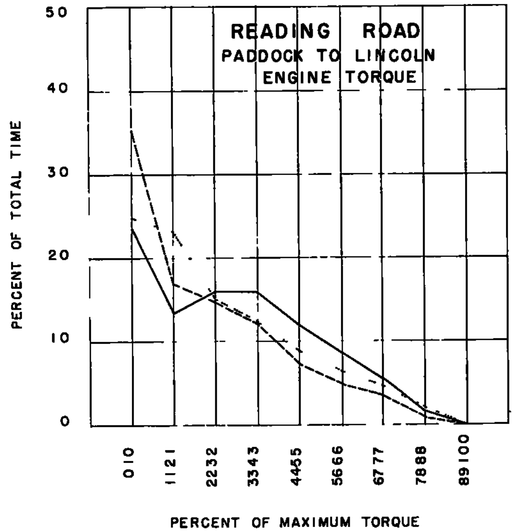


Figure 16. Time versus engine torque for Reading Road, Paddock to Lincoln.

total delay time (time in which the vehicle is at a full stop in traffic) on each test run. For a given test vehicle, operating on a given roadway, and within a normal range of urban operating speeds, the fuel consumption increases directly as the total delay time. Figure 18 illustrates this relationship on one section of Reading Road. On the Reading Road studies, in both 1952 and 1954, a 1952 Ford 6 two-door sedan was used. During the 1954 studies it was found that on Reading Road this vehicle was using between 0.0165 gal. and 0.020 gal. additional fuel for each 60 seconds of delay in traffic. By using this information it was possible to arrive at approximate fuel-consumption figures for the 1952 studies when the statistical testing equipment was not available.

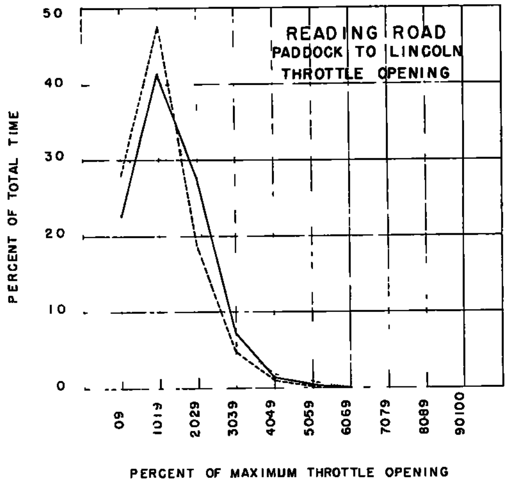


Figure 17. Time versus throttle opening for Reading Road, Paddock to Lincoln.

Figures are frequently given for a specific decrease in fuel economy with a given number of stops per mile. These studies did not show any such definite relationship, except that, in general, when there are a greater number of stops on a test run there is more total delay time which, in turn, affects fuel economy.

The studies showed a general relationship between the average operating speed, and the fuel economy. However, individual tests showed large variations in this relationship, as shown in Figure 19, and it appears likely that in the range of speeds encountered in urban driving, the relationship is due more to the effects of the delay time which affects the average operating speed rather than the speed itself.

Other general relationships which the studies showed are inverse ones between the average operating speed and fuel economy, and the amount of braking. Sufficient data were not obtained to establish numerical values for these relationships, but it appears definite that an increase in operating speed and fuel economy is usually accompanied by a decrease in the time spent in braking. Figure 20 illustrates this for one section of Reading Road, showing the average time per mile spent in braking the vehicle (braking is assumed to be deceleration at a rate greater than 4 ft. per sec. per sec.), during the different time groups. In this example, during the evening peak hours, when the operating speed was 5.1 to 5.6 mph. slower, and the fuel economy 2.3 to 2.4 mpg. less than during the morning peak and off-peak hours, the time spent in braking was 45 percent greater. This is an important relationship because brak-

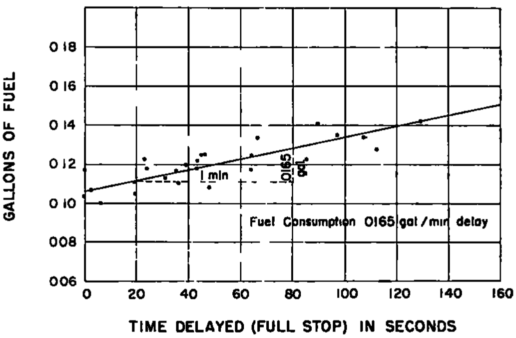


Figure 18. Fuel consumption versus delay for Reading Road, Paddock to Lincoln.

ing is an important factor in vehicle-maintenance costs of all types, affecting tire wear, brake life, and wear and tear on nearly all mechanical parts of the vehicle.

The relationships which these studies showed to exist indicate that statistical equipment of this type can be of great value in studying the effects of traffic flow on vehicle-operating characteristics. This type of study can be used in analyzing the efficiency of and effects of changes in traffic-control systems, in route evaluation, in comparisons of traffic flow on different thoroughfares at different times, under different traffic volume conditions, or other variables. A particular advantage is the fact that in the measurement of fuel consumption, a direct measurement is made of one of the largest single components in vehicle-operating expense. This permits a simpler analysis of the economic benefits or detriments of changes in traffic conditions than heretofore possible.

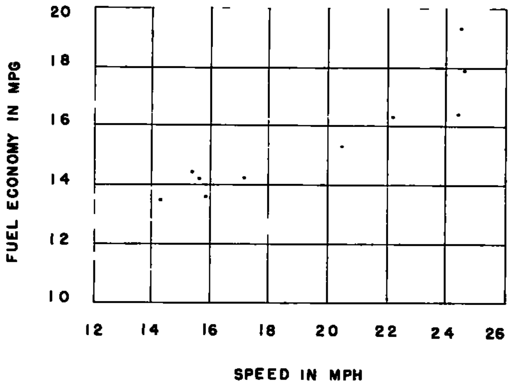


Figure 19. Fuel economy versus operating speed for Reading Road, Paddock to Lincoln.

Since most studies of this type are comparisons of two (or more) different operating conditions, it is obviously desirable to use the equipment for all portions of the studies, since the comparisons of operating characteristics can then be made directly. However, by means of the relationships between the traffic flow, or speed-and-delay data, and the operating characteristics, it is possible when the equipment is available for only a portion of the studies to obtain estimated data for the remainder of the studies, as was done for the 1952 Reading Road studies. It is possible that further research with equipment of this type may develop these studies to sufficient accuracy to permit estimates to be made of fuel consumption and

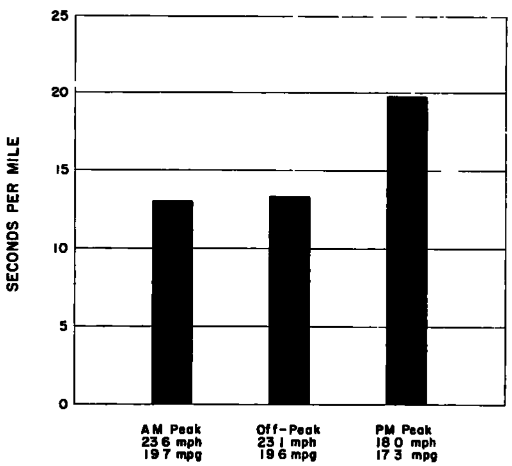


Figure 20. Braking time for Reading Road, Lincoln to Paddock.

changes in fuel consumption due to changes in traffic flow conditions, without the actual use of the equipment.

The relationship between delay time and extra fuel consumption, as shown in the 1954 studies using the statistical testing equipment, was used to estimate the change in fuel consumption per vehicle on Reading Road as compared to 1952. The studies showed that despite the increase in traffic volumes since 1952, substantial savings in fuel were realized by the motorists using the thoroughfare in 1954. The savings per individual vehicle were quite small (generally less than 0.025 gallon per trip between Broadway and Paddock), but the 17,500 vehicles using Reading Road during the 7-a.m.-to-6-p.m. test period on an average day used at least 180.8 gallons per day less fuel than would have been used by the same number of vehicles operating under 1952 traffic conditions.

This is believed to be a conservative figure because (1) the 1952 Ford 6 test car is believed to have at least average or better economy; (2) no consideration was given to extra fuel used by the 15 percent commercial traffic (trucks and buses) on Reading Road; (3) it is probable that savings in fuel were also realized by traffic using the thoroughfare during hours outside the 11-hour test period.

Using an estimated average gasoline price for Greater Cincinnati of 28 cents per gallon, the 180.8 gallons of gasoline per day would be a saving of $50.62 per day or on a yearly basis, a saving of approximately $18,500 per year.

SUMMARY

The first portion of this paper described the traffic control conditions on Reading Road prior to 1952 and the complete remodeling and modernization of the traffic signal system which took place in the winter of 1952-1953. The second portion of the paper described studies of statistics, speed-and-delay (or traffic-flow) characteristics, and vehicle-operating characteristics which were conducted in October 1952 and in April 1954.

These studies had as their objectives, first, to determine the effects on traffic operation of a modernized traffic-signal system which was installed between the time of the two studies; and second, to investigate the use of the statistical testing equipment in measuring the effects of traffic-flow characteristics on vehicle-operating characteristics. From the studies the following conclusions were reached.

1. Although traffic volumes on Reading Road between Broadway and Paddock has increased from 10 to 15 percent in 1954 as compared with 1952, traffic-flow characteristics have improved due to revisions in the traffic control system, so as to provide substantial savings to motorists using Reading Road in the form of a reduction in losses due to accidents, reduced fuel consumption, and time saved due to higher average operating speeds and less delay time in traffic. The total savings, on a monetary basis, amounted to at least $140,000 per year. The original cost of the modernized traffic-control system was approximately $85,000, so the savings in one year alone are greater than the first cost of the modernized system.

2. Statistical testing equipment, of the type developed by the Committee on Vehicle Characteristics of the Highway Research Board, should be extremely valuable in the analysis of the effects of traffic-flow characteristics on vehicle operating characteristics. The value of the equipment lies both in its use in making direct comparisons of vehicle operating characteristics under different traffic flow conditions and in its use in discovering general relationships between traffic flow conditions and vehicle operating characteristics.

City street capacity is increasing slowly, if at all, but traffic volumes have been growing tremendously. It has become mandatory that emphasis must be placed on positive traffic control that will, in every possible way, assist the movement of traffic. Adequate traffic flow information and proper signalization are only steps in this direction, but they should be exploited to the limit on existing facilities.

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Economics of Operation on Limited-Access Highways

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● MANY miles of the highway system of the United States are inadequate for present and future traffic needs, not necessarily because these highways are structurally deficient but primarily because they are geometrically and functionally inadequate. This geometric or functional inadequacy is caused by intersectional, medial, internal, and marginal interferences which contribute to an increase in highway accidents, and increase in the operating cost of motor vehicles, an increase in travel time, a reduction in highway capacity, and a decrease in the value of the highway investment.

In general, highways serve through traffic, provide access to abutting property, facilitate the needs of the general public, and contribute to the needs of national defense. These functions often create geometric inadequacies through conflict of use. For example, traffic on a highway that serves abutting property has the characteristics of low to moderate speed and of frequent turning movements. These do not blend with the characteristics of through traffic of high speeds and few turning movements. Therefore, in this era of specialization, it may be economical to construct separate highways for specific types of traffic.

Forty states have attempted to minimize highway interference by constructing sections of highways for which the prime purpose is to serve through traffic. These sections are often designated as freeways, expressways, parkways, limited-access highways, or controlled-access highways. A limited-access highway or a controlled-access highway is a "highway or street especially designed for through traffic, and over, from, or to which owners or occupants of abutting land or other persons have no right or easement or only a restricted right or easement of access, light, air, or view by reason of the fact that their property abuts upon such limited access facility or for any other reason" (1).

The design of limited-access highways varies from state to state. Some general features include: (1) restriction of access, (2) median strips, (3) multi-lanes, (4) wide right-of-way, (5) strict control of vertical and horizontal alignment, (6) land service roads, (7) elimination of highway intersections at grade, (8) elimination of railroad crossings at grade, and (9) prohibition of billboards and commercial signs (1).

Early English law provided for right of access to public roads to be enjoyed by all, and the term "highway" referred to a route to which the public at large had the right of access (2). The transition to limited-access highways has been deterred because of the historical background of public access to all highways. In recent years, however, there has been a tendency to shift from full public access to restricted access on certain portions of the present highway system.

Studies have been made of certain limited-access highways, of the legal aspects of limited-access highways, and of certain design characteristics and are reported in the literature. Little study, however, has been made of the economics of operation on limited-access highways.

PURPOSE

The purpose of this study is to evaluate certain benefits of several limited-access highways by making a comparison of some of the effects of limited and non-limited-access highways.

COLLECTION OF DATA

The case-study approach was used in the comparison study, and each study included two abutting or nearby sections of highway which were similar, except for access control. By using this approach, the assumption was made that had the access to the limited-access highway not been controlled, the characteristics (sav-

Form PR-761

[illegible] DEPARTMENT OF COMMERCE
[illegible] PUBLIC ROADS

ACCIDENT EXPERIENCE RELATED TO CONTROL OF ACCESS

State: OHIO

CONTROL OF ACCESS (AASHO definition)	Controlled Access Route (Check one)	Comparable Route (Check one)
	X Partial	___ Partial X None
Section of highway and/or route number	U.S. Rt. 40, Clark County	US Rt. 40, Franklin County
Termini of study	From Springfield to Vienna	Madison County Line to Columbus
Length - miles (nearest .01 mile)	7.4	7.5
Specify rural or urban area	Rural	Rural
Specify type of area as business, residential, industrial, or other	Agricultural and Residential	Industrial and Agricultural
Flat, rolling or mountainous	Rolling	Flat
Number of through traffic lanes	4	4
Number and width of roadways	2- 24'	2-24'
Width of median	30'	10'-30'
Width of shoulder or parking lane	10'	10'
Annual average daily traffic	7600	11000
Time period	1951	1951
Annual vehicle-miles	20.5 Million	30.2 Million
Percent commercial	18%	19%
Speed limit	50 m.p.h.	50 mph.
Average running speed	50 m.p.h.	50 m.p.h.
Number of intersections signalized	0	1
Number of driveways to roadside businesses	34	70

Figure 1. Route Comparison Form.

VEHICLE OPERATING CHARACTERISTICS
BUREAU OF PUBLIC ROADS TESTS

Employing equipment developed by HRB Committee on Vehicle Characteristics

Test No. 1-N Date June 10, 1954

Route U S Rt 40, Clark County, Springfield to Vienna

Remarks Ohio, Case Study No. 10, Controlled Access

SPEED

Counter No.	1	2	3	4	5	6	7	8	9	10	Total counts
Speed, MPH	0-5	6-8	9-11	12-18	19-23	24-35	36-46	47-56	57-68	69 & up	
Finish	038	125	929	753	003	555	28137	92278	01682	469	
Start	038	125	929	753	003	551	28125	92020	01482	469	
Difference	0	0	0	0	0	4	12	258	200	0	474
% Total											

GASOLINE CONSUMPTION

Counter No.	1	2	3	4	5	6	7	8	9	10	Total counts
Speed, MPH	0-5	6-8	9-11	12-18	19-23	24-35	36-46	47-56	57-68	69 & up	
Finish	763	415	643	515	924	243	651	56058	10731	101	
Start	763	415	643	515	924	242	651	55843	10555	101	
Difference	0	0	0	0	0	1	0	215	182	0	404
% Total											

BRAKING

Counter No.	1	2	3	4	5	6	7	8	9	10	Total counts
Deceleration	0-3	4-7	8-10	11-13	14-16	17-19	20-23	24-26	27-29	30 & up	
Finish	15523	69957	009	477	123	443	447	103	668	107	
Start	15053	69953	009	477	123	443	447	103	668	107	
Difference	470	4	0	0	0	0	0	0	0	0	474
% Total											

ENGINE TORQUE

Counter No.	1	2	3	4	5	6	7	8	9	10	Total counts
% Torque	Coast	0-10	11-21	22-32	33-43	44-55	56-66	67-77	78-88	89-100	
Finish	300	435	457	648	364	428	136	979	383	270	
Start	300	405	415	398	239	403	134	979	383	270	
Difference	0	30	42	250	125	25	2	0	0	0	474
% Total											

THROTTLE OPENING

Counter No.	1	2	3	4	5	6	7	8	9	10	Total counts
% Opening	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	90-100	
Finish	981	440	207	621	001	343	667	150	491	320	
Start	971	415	167	408	887	313	650	135	486	320	
Difference	10	25	40	213	114	30	17	15	5	0	474
% Total											

ODOMETER

Finish	406 28
Start	398 88
Trip Mileage	7.40

CLOCK

Finish	10 17 AM
Start	10 07 AM
Trip Time	8

MASTER COUNTER

Finish	51741
Start	51273
Total Counts	474

Trip Average Speed 56.3 MPH Trip Average Gas Consumption 18.3 MPG

Figure 2. Field Data Sheet.

ings of time, operating costs, and safety) of this route would be similar to the uncontrolled access section. Twelve case studies were included in the study.

The studies were selected to include examples of two-lane and four-lane highways in urban and rural areas, in flat and rolling topography, with a great variance in volume of traffic, with full and partial control, and from various geographical areas of the United States. The routes were selected with the aid of several state highway departments, the Bureau of Public Roads, and by field inspection. A form developed by the Bureau of Public Roads was used in selecting test sections and is shown in Figure 1. A typical set of data is shown in this figure.

The test vehicle was a 1952 two-door Pontiac with a standard gearshift, and the recording apparatus was installed on the test vehicle at General Motors Proving

Grounds in June 1954. The recording apparatus was used during June and July and returned to the proving grounds in August 1954. This apparatus was developed in 1950 under the auspices of the Highway Research Board Committee on Vehicle Characteristics in cooperation with the automotive industry. A report describing this equipment was presented at the thirtieth annual meeting of the Highway Research Board (3). The recording apparatus has 51 counters which automatically record the recording the field data of this study. At the start of each run the 51 counters were read and the values recorded in their appropriate spaces in the form, and at the end of each run the counters were again read and the values recorded in their appropriate spaces. The differences between the start and finish readings were the results of that particular test run. A typical set of values is shown in this figure. The unit of measurement for speed, braking, engine torque, and throttle opening was

Time Period Covered January 1 1951 to December 31 1951 — Page 2 of 2 Pages

ACCIDENT RECORD	Controlled Access Route							Comparable Route						
	Manner of accident						Total number of accidents	Manner of accident						Total number of accidents
	Rear end or side-swipe 1	Head on or side-swipe 2	Angle collision	Collision with pedestrian	Other collision	Non collision		Rear end or side-swipe 1	Head on or side-swipe 2	Angle collision	Collision with pedestrian	Other collision	Non collision	
All accidents	8	3	1	0	19	14	45	32	1	6	1	33	10	83
Fatal accidents	0	0	0	0	0	0	0	0	1	0	0	0	0	1
Injury accidents	3	0	1	0	6	7	17	10	0	3	1	11	7	32
Property damage accidents	5	3	0	0	13	7	28	22	0	3	0	22	3	50
Persons killed	0	0	0	0	0	0	0	0	2	0	0	0	0	2
[illegible]	5	0	2	0	15	12	34	14	2	4	1	15	9	45
[illegible]							220							275
[illegible]							0							6.3

Form PR-761

Figure 3. Accident Reporting Form.

important operating characteristics of the vehicle that might be affected by highway design. These operating characteristics were speed (used to evaluate savings in time), gasoline consumption, deceleration, and acceleration (used to evaluate operating costs).

A special form developed by the Bureau of Public Roads (Figure 2) was used for seconds, while for gasoline consumption the unit of measurement was one thousandths of a gallon of gasoline.

There were between six and ten test runs on each section of the controlled and uncontrolled highways, depending upon the length of the section and consistency of results. Certain statistical tests were made of the field data to determine the significant differences between the controlled-access sections of each study. Additional statistical tests were made to determine whether or not degree of urbanization and type of access control significantly affected operating characteristics on the highways.

uncontrolled-access sections for the 12 case studies is shown in Table 2. The difference in speed between the controlled and uncontrolled access sections for each case study is also given. The speed on the controlled access sections varied from 41.7 mph. to 55.9 mph., with an average for the 12

TABLE 1

COMPARATIVE ROUTES IN LIMITED ACCESS FIELD STUDY

STUDY NUMBER	STATE	ROUTE	LOCATION	ACCESS CONTROL	GEOMETRIC DESIGN
1	Connecticut	Connecticut 15	NE of Hartford	Full	4-Lane Divided
	Connecticut	Connecticut 15	SW of Hartford	None	4-Lane "
2	Georgia	Atlanta Expressway	In Atlanta	Full	6-Lane "
	Georgia	Atlanta Bypass	In Atlanta	None	6-Lane "
3	Georgia	US 41	North of Marietta	Partial	4-Lane "
	Georgia	US 41	Around Marietta	None	4-Lane "
4	Indiana	Tri-State Expressway	In Hammond	Full	4-Lane "
	Indiana	US 20	In Gary	None	4-Lane "
5	Louisiana	US 71	Alexandria Bypass	Partial	4-Lane "
	Louisiana	US 190	Baton Rouge Bypass	None	4-Lane "
6	Maine	US 1	Freeport Cutoff	Partial	2-Lane
	Maine	US 201	North of Augusta	None	2-Lane
7	Massachusetts	Massachusetts 128	Around Boston	Full	4-Lane Divided
	Massachusetts	US 9	West of Boston	None	4-Lane "
8	Massachusetts	Massachusetts 128	Around Boston	Partial	4-Lane "
	Massachusetts	US 1	North of Boston	None	6-Lane "
9	Michigan	Michigan 112	West of Detroit	Full	4-Lane "
	Michigan	US 112	West of Detroit	None	4-Lane "
10	Ohio	US 40	East of Springfield	Partial	4-Lane "
	Ohio	US 40	West of Columbus	None	4-Lane "
11	Ohio	US 22	Around Clarksville	Partial	2-Lane
	Ohio	US 22	North of Clarksville	None	2-Lane
12	Rhode Island	Rhode Island 147	So. of Uncontrolled Section	Full	4-Lane Divided
	Rhode Island	Rhode Island 147	South of Woonsocket	None	4-Lane "

In addition to the operating characteristics, accident reports were obtained from the state highway departments for each test section in order to evaluate the differences in safety. The Bureau of Public Roads had previously requested similar information; therefore, the information received by the Bureau is used in this report. The accident reporting form is presented in Figure 3, and a typical set of data is shown in this figure. The results of similar studies were obtained as well as accident experience on toll roads in order to provide a comparison with results of the twelve case studies. The twelve case studies are listed in Table 1.

RESULTS OF THE CASE STUDIES

The data collected in the individual case studies are compared with the data of similar case studies in the following sections, and the data from all the case studies are then combined in order to determine the overall effect of control of access to the road user. The data are evaluated on the basis of travel time, operating costs, and highway safety.

Travel Time

The average speed on the controlled- and uncontrolled-access sections for the 12 case studies is shown in Table 2.

studies of 48.2 mph. The speed on the uncontrolled access sections varied from 18.5 mph. to 48.9 mph. with an average for the 12 case studies of 38.3 mph. The difference in speed in a particular case study varied from 2.1 mph. in Study 8, to 23.3mph. in Study 2, and the average difference of the studies was 9.9 mph. The average time required to travel a mile on each test section and the savings in time for each case study are also given in Table 2.

The average speeds for the 12 case studies are summarized in Table 3 by type of access control and degree of urbanization. The data in this figure may not be adapted to all highways, because of the relatively small number of test sections. However, the table does give an indication of the approximate average speeds under various highway conditions. The number in parenthesis indicates the number of test sections included in the average speed.

Average speeds on the fully controlled-access highways appear to be only slightly affected by degree of urbanization, whereas average speeds on partially controlled and uncontrolled sections appear to decrease with increased urbanization. In rural areas there appears to be little difference between the average speeds on fully and partially controlled-access highways, whereas in suburban, and probably more so in urban areas, the average speed on fully controlled-access sections is greater than on partially controlled sections. The difference in average speeds between full-controlled and uncontrolled sections in rural, suburban, and urban areas is 2.5, 10.3, and 20.9 mph., respectively. Assuming these speed differences at the average speeds, there would be a time savings of 0.07, 0.32, and 1.00 minutes per vehicle-mile of travel. In other words, it takes 8, 26, and 79 percent more time, respectively, to travel a mile on the uncontrolled-access highway than on the controlled-access highway.

If the value of time for passenger cars and commercial vehicles is taken as $1.35 per hour (2¼ cents per minute) and $3 per hour (5 cents per minute) for a highway carrying 80 percent passenger cars and 20 percent commercial vehicles, the composite value of time would be $1.68 per hour (2.8 cents per minute). The monetary time savings on fully controlled-access highways in rural, suburban, and urban areas would be 0.2 cents, 0.9 cents, and 2.8 cents per vehicle-mile. As a further example, if the access to a highway carrying 10,000 vehicles per day were fully controlled, the monetary time savings per mile would amount to $7,200; $32,800; and $102,000 per year.

The difference in average speeds between partially controlled and uncontrolled sections in rural and suburban areas is 4.6 and 3.4 mph., respectively. The average speed in urban areas on partially controlled-access highways would probably have a great variation, depending upon the degree of access control. Assuming these speed differences at the average speeds, there would be a time savings of 0.13 and 0.12 minutes per vehicle-mile of travel. Again using the value of time indicated in the previous paragraph, the monetary time savings on partially controlled access highways in rural and suburban areas would be 0.4 and 0.3 cents per vehicle-mile. If the access to a highway carrying 10,000 vehicles per day was partially controlled, the monetary savings per mile would amount to $13,200 and $12,300 per year.

The case studies not only point out that the average speed on the controlled-access highways is higher, but also that the speed is more uniform over the length of the route. Figure 4 presents the average speed characteristics of the combined 12 studies, and indicates that 90 percent of the travel on the 12 controlled-access sections was at speeds between 36 and 56 mph., while only 74 percent of the travel on the 12 uncontrolled-access sections was between the same speeds. Ten percent of the travel on the uncontrolled access sections was at speeds less than 24 mph.

The uniform speed on the controlled-access highways as compared with the uncontrolled-access highways is important, for uniform speeds generally result in increased safety, increased capacity, and reduced operating costs.

TABLE 2

AVERAGE SPEED IN MILES PER HOUR ON THE CONTROLLED AND UNCONTROLLED ACCESS SECTIONS FOR THE TWELVE CASE STUDIES

Case Study No.	Controlled Section	Uncontrolled Section	Difference in Speed	Savings in Time (minutes)
1	49.2 (1.22)*	41.3 (1.45)	7.9	0.23
2	41.7 (1.44)	18.5 (3.24)	23.2	1.80
3	45.2 (1.33)	36.6 (1.64)	8.6	0.31
4	53.0 (1.13)	34.2 (1.75)	18.8	0.62
5	42.3 (1.42)	37.4 (1.60)	4.9	0.18
6	50.4 (1.19)	42.7 (1.40)	7.7	0.21
7	48.4 (1.24)	36.7 (1.63)	11.7	0.39
8	41.8 (1.44)	39.7 (1.51)	2.1	0.07
9	49.2 (1.22)	38.8 (1.54)	10.4	0.32
10	54.3 (1.10)	41.7 (1.44)	12.6	0.34
11	55.9 (1.07)	48.9 (1.22)	7.0	0.15
12	46.4 (1.29)	43.2 (1.39)	3.2	0.10
Average	48.2 (1.25)	38.3 (1.57)	9.9	0.32

*Numbers in parantheses are the average time in minutes required to travel one mile on that particular section of highway.

Operating Costs

Gasoline consumption and utilization of brakes were two of the components of operating costs which were obtained for the case studies. Since these are not the only components of operating costs, the overall operating costs could not be evaluated on a monetary basis.

The average gasoline consumption on the controlled- and uncontrolled-access sections is shown in Table 4. The difference in gasoline consumption between the sections is also given. Although the gasoline consumption on some of the controlled-access highways was better (more miles per gallon) than on comparative uncontrolled sections, nevertheless the combined studies indicated that there was not an appreciable difference in gasoline consumption. In fact, 19.1 mpg. was the average gasoline consumption on the uncontrolled sections as compared with 18.9 mpg. on the controlled sections. This indicates that loss in gasoline mileage due to marginal and intersectional friction may often be less than gasoline mileage lost due to travel at higher speeds. This points out again that time must be of value to motorists, for they will attempt to save time on the controlled sections, even at the expense of increased gasoline consumption.

TABLE 3

AVERAGE SPEED IN MILES PER HOUR BY TYPE OF ACCESS CONTROL AND DEGREE OF URBANIZATION FOR THE TWELVE CASE STUDIES

	Urban	Suburban	Rural
Full Control	47.3 (2)*	49.2 (2)	47.4 (2)
Partial Control	-	42.3 (1)	49.5 (5)
No Control	26.4 (2)	38.9 (7)	44.9 (3)

* Numbers in parentheses indicate the number of test sections included in the average speeds.

The average gasoline consumption is summarized in Table 5 by type of access control and by degree of urbanization. As pointed out in the discussion of average speeds, the size of the sample is rather small, and there appears to be certain relationships that do not seem plausible at first glance. Further investigation revealed that average speed appeared to have as great an influence on gasoline consumption as either access control or degree of urbanization.

The relationship between gasoline consumption and average speed is plotted on Figure 5. The points on the curve were established by averaging the average speeds and their gasoline consumption on the test sections in groups of 30-35, 35-40, 40-45, 45-50, and 50-56 mph. The curve established with the same equipment on a 1951 Pontiac by A. J. Bone (4) is superimposed on the graph. Some of the points on Bone's curve, particularly the points at the higher speeds, were determined by test runs on the test sections given in Study 7 of this report. The other points on Bone's curve were obtained from routes different from those selected by this study and the test vehicles were not the same. This would have some bearing on the differences in the two studies in relationship to gasoline consumption and speed.

The graph indicates that gasoline consumption is dependent upon the speed the vehicle operator desires to drive. If the vehicle operator would drive at the speed of optimum gasoline consumption (30 to 40 mph.) on the average controlled-access sections, the gasoline consumption of the test vehicle would be approximately 20.1 mpg. This choice of speed on the controlled-access highway is the drivers' and generally not dependent upon road and traffic conditions, which do determine the speed on the uncontrolled sections.

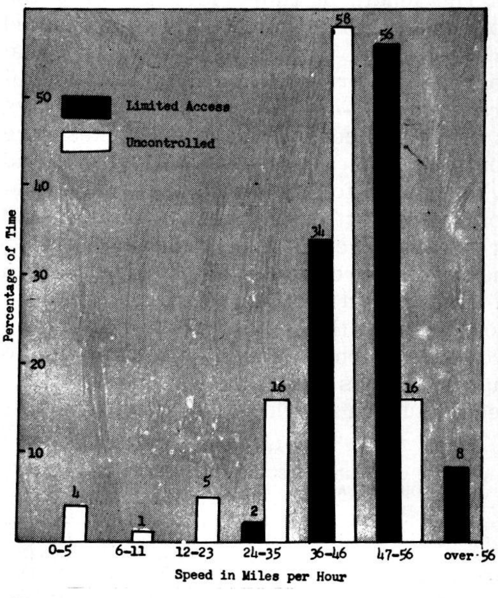

Figure 4. Average Speed Distribution of the Twelve Case Studies.

The conclusion from the gasoline-consumption data is that gasoline consumption could be lower on the controlled-access sections if the vehicle operator would drive 30 to 40 mph. Time savings on the controlled-access sections, of course, would then be reduced. However, under existing driver behavior, gasoline consumption on the rural and suburban sections of highway is not appreciably different. On urban sections of highway, the decrease in miles per gallon of gasoline consumption is due to greater congestion and traffic friction, rather than the decrease due to above optimum speeds. This results in better gasoline consumption on the controlled-access sections.

on rural, suburban, and urban areas, respectively. Applying the above values to a highway carrying 10,000 vehicles per day, the reduction in length of time of brake application would amount to 172, 1,720 and 5,820 hours per mile per year.

TABLE 4

AVERAGE GASOLINE CONSUMPTION ON THE CONTROLLED AND UNCONTROLLED ACCESS SECTIONS FOR THE TWELVE CASE STUDIES

Case Study No.	Gasoline Consumption (miles per gallon) Controlled Sections	Uncontrolled Sections	Difference
1	19.2	19.0	0.2
2	20.7	16.5	4.2
3	20.3	20.2	0.1
4	17.0	18.9	-1.9
5	19.8	21.4	-1.6
6	17.4	19.0	-1.6
7	19.3	19.3	0.0
8	19.2	19.8	-0.6
9	19.7	20.8	-1.1
10	18.3	18.7	-0.4
11	17.3	17.0	0.3
12	18.3	19.1	-0.8
Average	18.9	19.1	-0.2

The length of time (seconds) of brake application per mile of travel is presented in Table 6 by type of access control and degree or urbanization. Application of brake on full-controlled-access highways is rarely needed, whereas brakes are applied on the average of 0.21, 1.70, and 5.74 seconds for each mile of travel on uncontrolled sections in rural, suburban, and urban areas respectively. In rural areas, the brakes were applied for a greater length of time on partially controlled-access sections than for the fully controlled or uncontrolled sections. This is probably due to higher speeds with an occasional unexpected sudden slowing down or stopping.

TABLE 5

AVERAGE GASOLINE CONSUMPTION BY TYPE OF ACCESS CONTROL AND DEGREE OF URBANIZATION

	Urban	Suburban	Rural
Full Control	18.8 (2)*	19.4 (2)	18.8 (2)
Partial Control	-	19.8 (1)	18.5 (5)
No Control	17.7 (2)	19.9 (7)	18.4 (3)

* Numbers in parentheses indicate the number of test sections included in the average gasoline consumption.

The utilization of the brakes is reduced when access is fully controlled by 0.17, 1.70 and 5.74 seconds per mile of travel

TABLE 6

AVERAGE LENGTH OF TIME OF BRAKE APPLICATION PER MILE BY TYPE OF ACCESS CONTROL AND DEGREE OF URBANIZATION FOR THE TWELVE CASE STUDIES

	Urban	Suburban	Rural
Full Control	0.00 (2)*	0.00 (2)	0.04 (2)
Partial Control	-	0.00 (1)	0.42 (5)
No Control	5.74 (2)	1.70 (7)	0.21 (3)

* The unit of duration of brake application is seconds per mile and the numbers in parentheses indicate the number of test sections included in the average brake application.

Highway Safety (Twelve Case Studies)

The accident and fatality rates are shown in Table 7. Most of these rates cover only a one-year period. The average accident rates for the controlled-and uncontrolled-access sections were 136 and 327 accidents per 100 million vehicle-miles, respectively. The average fatality

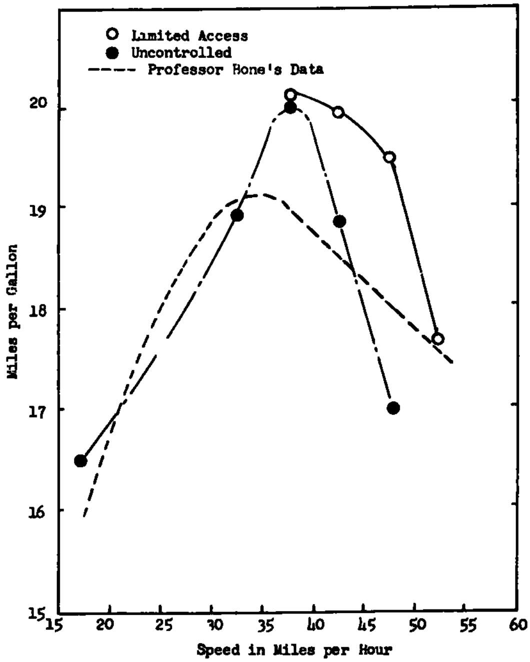

Figure 5. Gasoline Consumption Related to Speed.

rate for the controlled and uncontrolled sections was 3.2 and 7.4 fatalities per 100 million vehicle-miles, respectively. There were 2.4 times as many accidents per 100 million vehicle-miles on the uncontrolled sections as the controlled sections and 2.3 times as many fatalities per 100 million vehicle-miles. If the above accident and fatality rates were long-run averages for all roads of the two types, controlling the access on a 6.5 mile stretch of highway carrying 10,000 vehicles per day would be expected to save one life and reduce the number of accidents by 45 each year. However, each of the rates given in Table 7 is subject to year-to-year variation. The table gives an estimate of the standard error for each observed accident and fatality rate. It is practically certain that corresponding rates over a longer period of time would fail within two standard errors of the rates reported in Table 7.

pears to be low when compared with data collected by the Bureau of Public Roads, which will be presented later in this report.

The small number of test sections included in the case studies to measure relatively small occurrences, such as highway fatalities, is insufficient to draw any definite conclusions as to the effect of access control and degree of urbanization. Later in this section additional data will be presented to determine the relationship of fatalities to type of access control and degree of urbanization.

Even on the best-designed, full-controlled-access highways—where marginal, intersectional, medial, and internal frictions are almost eliminated—accidents and loss of lives continue to occur. The question is obviously what kind of accidents and fatalities still occur and what causes them. In order to make this analysis, accidents on the test sections were combined

TABLE 7

ACCIDENT AND FATALITY RATES ON THE CONTROLLED AND UNCONTROLLED ACCESS SECTIONS FOR THE TWELVE CASE STUDIES

Case Study No.	Data for Year	Accident Rate				Fatality Rate			
		Controlled		Uncontrolled		Controlled		Uncontrolled	
		Rate*	ESE**	Rate	ESE	Rate	ESE	Rate	ESE
1	1946-52	150	15	300	16	0.9	1.1	8.1	2.7
2	1953	151	26	435	38	4.4	2.5	0.0	-
3	1953	165	24	333	25	3.4	3.4	0.0	-
4	1953	465	68	457	57	20.0	14.2	7.1	7.1
5	1953	320	39	648	55	0.0	-	6.2	5.4
6	1953	176	44	133	42	0.0	-	0.0	-
7	1952	46	5	364	18	1.1	.8	2.1	1.5
8	1952	278	31	428	28	3.4	3.4	3.6	2.5
9	1952	115	11	383	29	6.7	2.7	15.0	5.7
10	1951-52	232	33	273	30	2.5	3.5	9.8	5.7
11	1951-52	156	46	450	125	3.2	6.6	0.0	-
12	1953	103	33	167	37	10.3	10.2	0.0	-
Average***		136		327		3.2		7.4	

* The units of the values under rate represent accidents or fatalities per 100 million vehicle-miles.
** ESE = Estimated Standard Error.
*** Weighted on basis of vehicle-miles.

These rates serve as the basis for all comparisons and factual statements which are made in the remainder of this paper, and so any conclusions are relative to only the roads which were in the case studies and the years for which the accident data was obtained.

Table 8 summarizes the accident and fatality rates by type of access control and degree of urbanization. The accident rate decreases with an increase in control of access with the exception of partially controlled highways in rural areas. The accident rate for the uncontrolled access sections in rural areas for this study ap-

as related to access control. Then the accidents and fatalities were summarized on the basis of 100 million vehicle-miles, as shown in Table 9. Sixty percent of the accidents on the fully controlled sections were of the rear-end or side-swipe type, 20 percent of the noncollision type, and 12 percent of the total were other collision. Sixty percent of the fatalities on the full-controlled-access sections occurred in rear-end or side-swipe accidents.

Another approach to the accident problem is to determine the percent difference of accidents as access is controlled and a summary of this analysis is shown in

Table 10. The greatest difference in accidents and fatalities on partially and fully controlled sections is for angle collisions and collisions with pedestrians. The smallest difference as access control increased is in rear-end or side-swipe and noncollision accidents.

In order to understand better the causes of accidents and fatalities on fully controlled highways, motor-vehicle reports were obtained from the Rhode Island Department of Public Works for the fully controlled access highway of Study 12. The following is the description of several of the accidents on the full-controlled-access highway:

1. "Vehicle 1, the truck, was parked on the highway. The driver had stopped to rearrange his load. Vehicle 2, car, ran into rear of truck." Result - one fatality.

2. "Driver lost control of car at curve north of Old Louisquisset Pike - Driver says car kept going to left - doesn't know what happened." Result - one person injured.

3. "Car 1 was passing a truck which had stopped in its lane to allow some birds to cross road. Car 2 following car 1 hit car 1 when car 1 saw birds and slowed down." Result - one injured person.

4. "Vehicle 1, the bus, was passing car 2. The right rear of the bus hit left front fender and side of car 2." Result - two injured persons.

5. "Car 1 following car 2 going south on Louisquisset. Car 2 slowed down suddenly and was hit in rear by 1 - weather very rainy." Result - four injured persons.

After reading the description of these accidents, improving the highways by controlling the access will not eliminate all the accidents and fatalities. Controlling the access will greatly reduce them, but the driver can still involve himself and others in accidents even on the best highways.

Highway Safety (Connecticut Study)

A study of accidents and fatalities on fully controlled, partially controlled and uncontrolled access highways was made (5) in Connecticut in 1953, and a summary of the study is presented in Table 11. The accident and fatality rates have been arranged in order to compare these rates with the accident and fatality rates of the 12 case studies shown in Table 8. The accident rates, as presented in the Connecticut study, in all cases are substantially greater than those obtained in the 12 studies, particularly on the uncontrolled-access highways. This is also true for the fatality rates, except in the case of fully controlled-access highways in urban areas.

Highway Safety (Bureau of Public Roads Study)

In October 1953 the Bureau of Public Roads distributed a memorandum (6) which was a summary of a preliminary study pertaining to accidents and fatalities as related to access control, and the tentative results of this study are presented in Table 12. The data represent over 1,000 miles of highways and over 12 billion vehicle-miles. The accident rates and fatalities in the Bureau of Public Roads study are also greater than those obtained in the case studies, and once again particularly on the uncontrolled-access sections.

TABLE 8

ACCIDENT AND FATALITY RATES BY TYPE OF ACCESS CONTROL AND DEGREE OF URBANIZATION FOR THE TWELVE CASE STUDIES

	Accidents**		
	Urban	Suburban	Rural
Full Control	247 (2)*	141 (2)	49 (2)
Partial Control	-	320 (1)	200 (5)
No Control	443 (2)	330 (7)	236 (3)
	Fatalities**		
	Urban	Suburban	Rural
Full Control	9.2 (2)*	2.5 (2)	1.6 (2)
Partial Control	-	0.0 (1)	9.0 (5)
No Control	2.3 (2)	6.9 (7)	0.0 (3)

* The values in the tables are the number of accidents and fatalities per 100 million vehicle-miles and the numbers in parentheses indicate the number of test sections included in the average speeds.

** See Table 7 for an indication of limitations of data and the resulting standard errors.

An overall comparison of the accident rates and fatality rates included in each study by type of access control and degree of urbanization for the 12 case studies, the Connecticut study, and the Bureau of Public Roads study is presented in Tables 13 and 14.

Table 13 indicates that the combined accident rates of the case studies are lower than the accident rates obtained in the Connecticut and Bureau of Public Roads studies, except on fully controlled-access highways in urban areas. This suggests that the controlled-and uncontrolled-access sections of highway in the 12 case studies may be better designed than sections included in the other two studies.

The Connecticut and Bureau of Public Roads studies indicate there is a greater reduction in accidents by access control in urban areas than in rural areas. The accident rates reported in the Connecticut study are higher on full-controlled-access sections and lower on uncontrolled-access sections than the accident rates as reported by the Bureau of Public Roads. Therefore the BPR study shows a greater reduction in accident rates by access control than the Connecticut study.

All three studies indicate that accident rates are $1\frac{1}{2}$ to 6 times greater on uncontrolled-access highways than on controlled-access highways.

TABLE 9

TYPES OF HIGHWAY ACCIDENTS AS RELATED TO ACCESS CONTROL

Accident Record		Manner of Accident: Rear-end or sideswipe	Head-on or sideswipe	Angle Collision	Collision with Ped.	Other Collision	Non-Collision	Total Accidents
All Accidents	F	82	4	6	1	16	27	136
	P	92	9	55	6	66	81	309
	N	197	12	108	12	73	34	436
Fatal Accidents	F	2			1	1		4
	P	2		3				5
	N	1		1	4	1		7
Injury Accidents	F	33		1		5	16	55
	P	27	2	12	6	19	34	100
	N	66	3	32	5	25	16	147
Property Damage	F	46	4	5		11	11	77
	P	64	8	38		47	47	204
	N	131	9	75		48	18	281
Persons Killed	F	3			1	1		5
	P	1		8				9
	N	2		1	4	2		9
Persons Injured	F	70		1		6	20	97
	P	48	2	23	16	36	62	187
	N	112	9	67	7	38	23	256

F indicates Full Control
P indicates Partial Control
N indicates No Control

All values in table are the number of accidents per 100 million vehicle-miles, and accidents of case studies 3, 6, 7, and 8 are not included.

TABLE 10

REDUCTION OF ACCIDENTS AND FATALITIES BY ACCESS CONTROL

Accident Record		Manner of Accident: Rear-end or sideswipe	Head-on or sideswipe	Angle Collision	Collision with Ped.	Other Collision	Non-Collision	Total Accidents
		%	%	%	%	%	%	%
All Accidents	F	58	67	94	92	78	21	69
	P	53	25	49	50	10	*	29
Fatal Accidents	F	*		100	75	0		43
	P	*		*	100	100		29
Injury Accidents	F	50	100	97	100	80	0	63
	P	59	33	62	*	24	*	32
Property Damage Accidents	F	65	56	93		77	39	73
	P	51	11	49		2	*	27
Persons Killed	F	*		100	75	50		44
	P	50		*	100	100		6
Persons Injured	F	37	100	99	100	84	7	72
	P	57	78	65	*	53	*	27

F indicates Full Control
P indicates Partial Control
* Actually an increase

The results of Table 14 indicate that the combined fatality rates of the 12 case studies are lower than the fatality rates obtained in the Connecticut and Bureau of Public Roads studies, except on full-controlled-access highways in urban areas. This again suggests that the controlled- and uncontrolled-access sections of highway in the 12 case studies may be better designed than sections included in the other two studies.

The Connecticut data suggests that fatality rates decrease with an increase in access control, while the Bureau of Public Roads data suggest that partial-controlled-access highways may have a higher fatality rate than uncontrolled-access highways.

TABLE 11

ACCIDENT EXPERIENCE RELATED TO CONTROL OF ACCESS IN CONNECTICUT

	Accidents	
	Urban	Rural
Full Control	261	221
Partial Control	180	250
No Control	725	313

FATALITY EXPERIENCE RELATED TO CONTROL OF ACCESS IN CONNECTICUT

	Fatalities	
	Urban	Rural
Full Control	1.9	3.0
Partial Control	0.0	5.9
No Control	5.7	6.7

The values in the tables are the number of accidents and fatalities per 100 million vehicle-miles.

The Connecticut and Bureau of Public Roads studies show that fatality rates are generally higher on rural sections of highway than on urban sections and that fatality rates are lowest on fully controlled-access highways.

Highway Safety (Toll Roads)

As of September 1954, there were 1,153 miles of toll roads in operation, 1,439 miles under construction, 2,708 miles authorized or ready to begin construction, and 2,640 miles in investigational or preliminary planning stage (7). With the growth of the number of miles of toll roads, it is of special interest to compare the accident and fatality rates of some of the existing toll roads with similar rates of fully controlled-access highways which are under public control. The accident and fatality rates (8, 9) on the New Jersey, Oklahoma, and Pennsylvania Turnpikes are shown in Table 15. Assuming that the toll roads have similar characteristics to the rural fully controlled-access-highways under public control, the accident rates on the toll roads are quite favorable. In fact, in general they appear to be slightly less than the accident rates on the comparable publicly owned highways. However, the fatality rates, as reported by all three studies, are less than the fatality rates of the three toll roads. There may be other factors, such as speed, which may have caused the discrepancy between the accident and fatality rates on the toll roads and the publicly owned roads.

TABLE 12

TENTATIVE RESULTS OF BUREAU OF PUBLIC ROADS STUDY RELATING ACCIDENT EXPERIENCE TO CONTROL OF ACCESS

	Accidents	
	Urban	Rural
Full Control	146	210
Partial Control	790	227
No Control	966	407
	Fatalities	
	Urban	Rural
Full Control	2.3	3.0
Partial Control	5.3	10.4
No Control	3.0	8.9

The values in the tables are the number of accidents and fatalities per 100 million vehicle-miles.

TABLE 13

COMPARISON OF ACCIDENT RATES AS RELATED TO ACCESS CONTROL

Type of Access Control	Urban	Rural
Full Access Control		
Twelve Case Studies	247	49
Connecticut Study	261	221
Bureau of Public Roads Study	146	210
Partial Access Control		
Twelve Case Studies	-	200
Connecticut Study	180	250
Bureau of Public Roads Study	790	227
No Access Control		
Twelve Case Studies	443	236
Connecticut Study	725	313
Bureau of Public Roads Study	966	407

The values in the table represent the number of accidents per 100 million vehicle-miles of travel.

TABLE 14

COMPARISON OF FATALITY RATES AS RELATED TO ACCESS CONTROL

Type of Access Control	Urban	Rural
Full Acess Control		
Twelve Case Studies	9.2	1.6
Connecticut Study	1.9	3.0
Bureau of Public Roads Study	2.3	3.0
Partial Access Control		
Twelve Case Studies		9.0
Connecticut Study	0.0	5.9
Bureau of Public Roads Study	5.3	10.4
No Access Control		
Twelve Case Studies	2.3	0.0
Connecticut Study	5.7	6.7
Bureau of Public Roads Study	3.0	8.9

The values in the table represent the number of fatalities per 100 million vehicle-miles of travel.

SUMMARY OF RESULTS

Results obtained from the 12 case studies of comparing controlled-access facilities with uncontrolled-access facilities:

1. The average speed on the fully controlled and partially controlled sections was higher in all 12 case studies than the average speed on comparable uncontrolled sections. The average speed on the combined twelve controlled sections was 48.2 mph., while the average speed on the com-

bined 12 uncontrolled sections was 38.3 mph., resulting in a difference between the two average speeds of 9.9 mph.

TABLE 15

ACCIDENT AND FATALITY RATES ON CERTAIN TOLL ROADS

	Accident Rate			Fatality Rate		
Year	New Jersey	Oklahoma	Pennsylvania	New Jersey	Oklahoma	Pennsylvania
1940			260			9.4
1941			218			10.7
1942			231			10.9
1943			244			8.0
1944			239			14.5
1945			166			11.2
1946			135			9.8
1947			137			5.8
1948			157			7.3
1949			157			10.0
1950			200			12.4
1951			126			8.5
1952	93		103	6.1		7.3
1953	67	94	136	4.1	3.8	7.3
Average	80	94	179	5.1	3.8	9.5

The values in the table represent the number of accidents and fatalities per 100 million vehicle-miles.

2. The average time savings on fully controlled-access highways as compared with uncontrolled-access highways in rural, suburban, and urban areas are 0.07, 0.32, and 1.00 minutes per vehicle-mile of travel, or on a monetary basis are 0.2, 0.9, and 2.8 cents per vehicle-mile of travel.

3. The average time savings on partially controlled-access highways as compared with uncontrolled-access highways in rural and suburban areas are 0.13 and 0.12 minutes per vehicle-mile of travel, or on a monetary basis are 0.4 and 0.3 cents per vehicle-mile of travel.

4. The average gasoline consumption on the combined sections was 18.9 mpg. as compared with 19.1 mpg. on the combined sections. Gasoline consumption did not appear to be as affected by access control or by degree of urbanization as it was by average speed.

5. The brakes were used 0.17, 1.70, and 5.74 seconds more per vehicle-mile of travel on the uncontrolled-access sections than on the full-controlled-access sections in rural, suburban, and urban areas, respectively.

6. For the period of time covered by the accident data there were 2.4 times as many accidents and 2.3 times as many fatalities per vehicle-mile of travel on the uncontrolled-access sections than on the comparable controlled-access sections.

CONCLUSIONS

The data of this study indicate that fully and partially controlled-access highways carrying substantial volumes of through traffic result in: (1) a significant savings in time and a significant reduction in gasoline consumption in urban areas; (2) a significant savings in time but no significant reduction in gasoline consumption in suburban areas; (3) no significant savings in time nor significant reduction in gasoline consumption in rural areas; and (4) a significant decrease in the accident rate in urban, suburban, and rural areas.

In view of the limitations of the fatality data and the resulting standard errors, no conclusion concerning a comparison of fatality rates can be made.

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