Operating Characteristics of a Passenger Car on Selected Routes

CARL C. SAAL, Chief, Vehicle Operations Section,
Highway Transport Research Branch, Bureau of Public Roads

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.

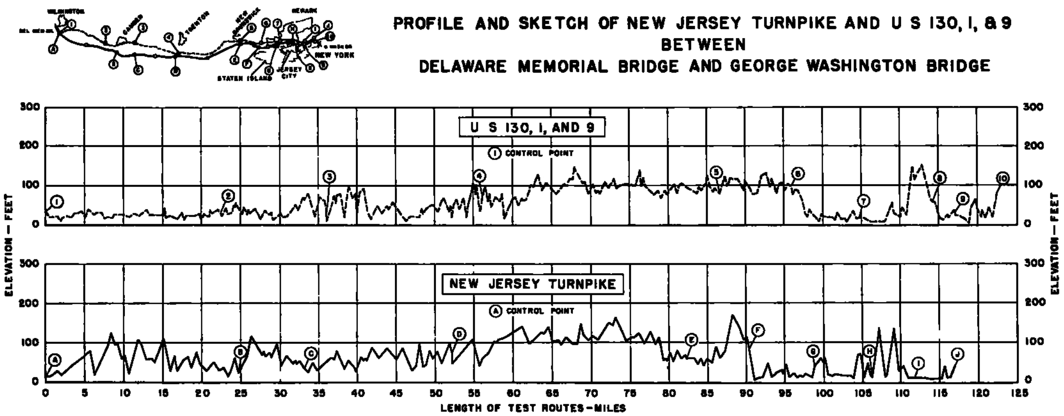

Figure 1.

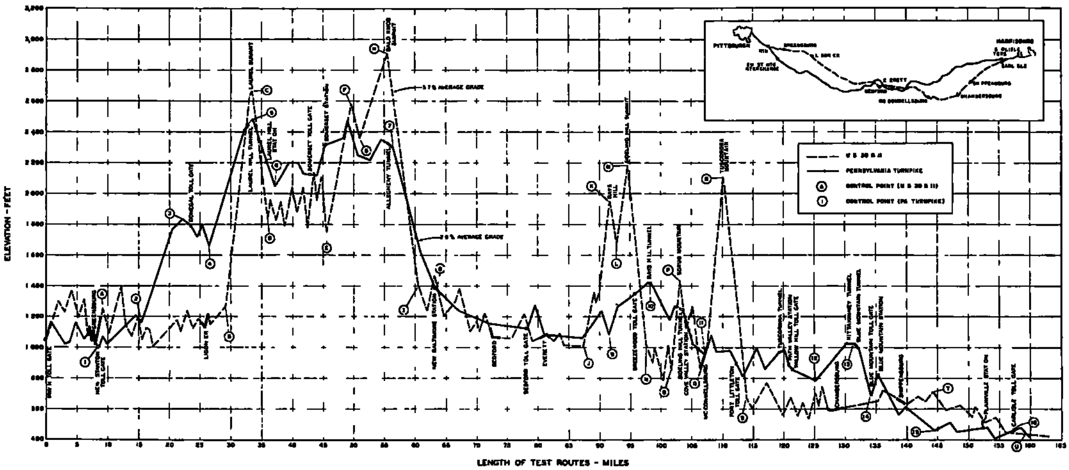

Figure 2.

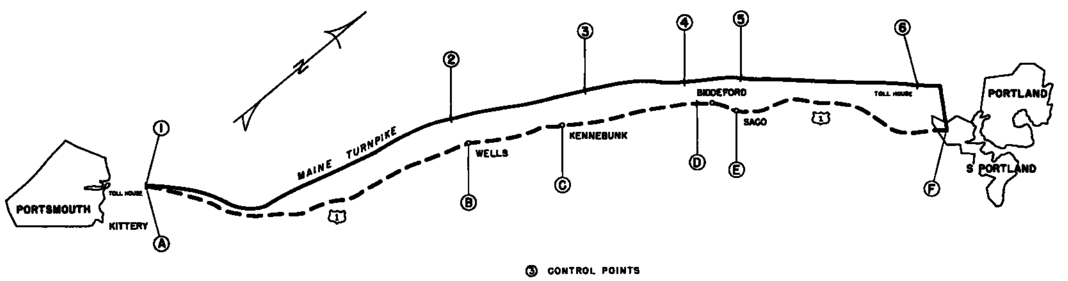

Figure 3.

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-

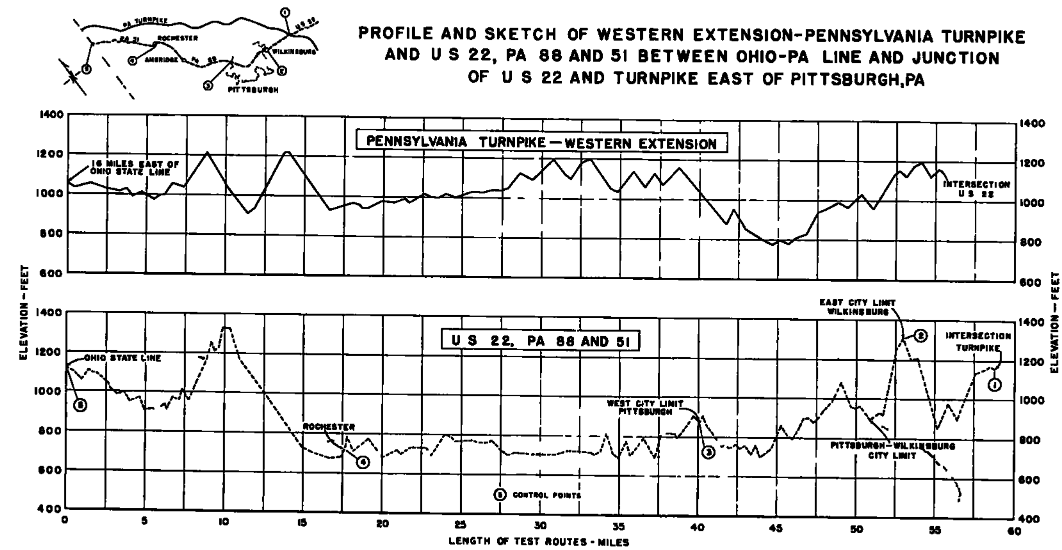

Figure 4.

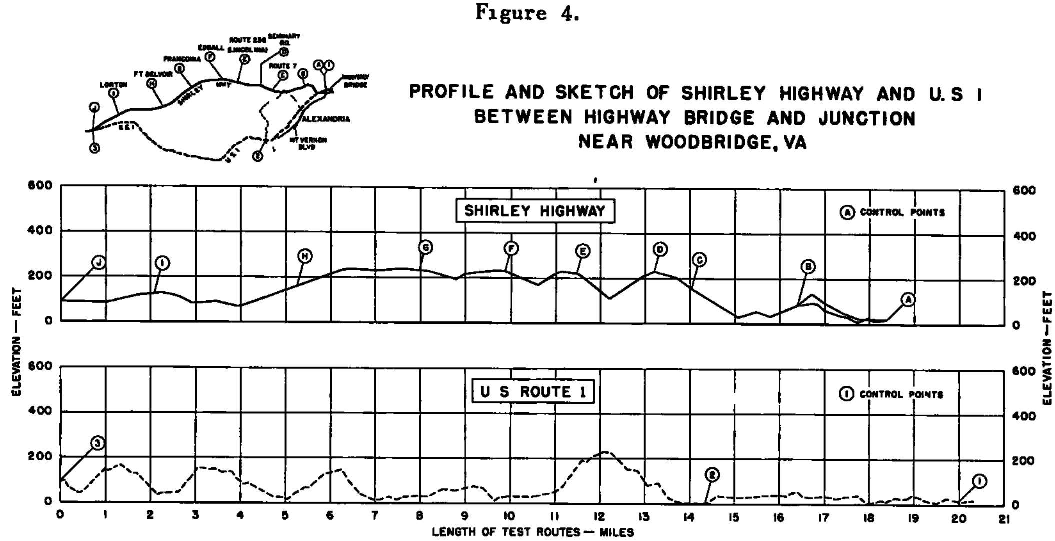

Figure 5.

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

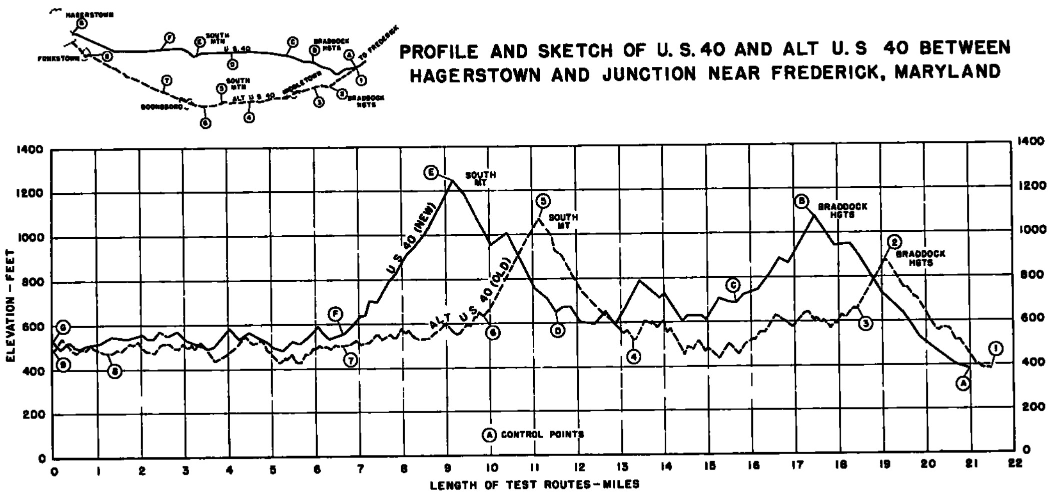

Figure 6.

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

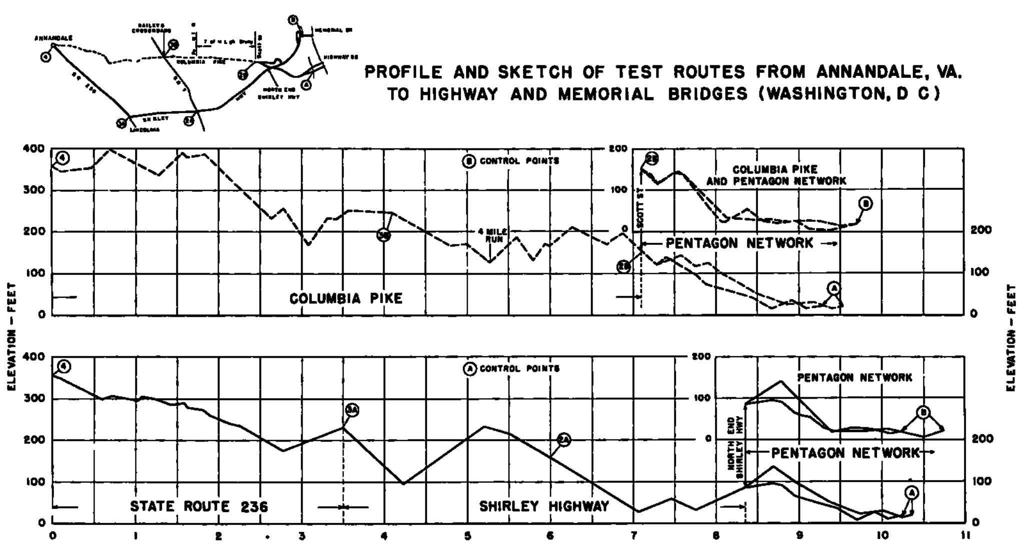

Figure 7.

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.

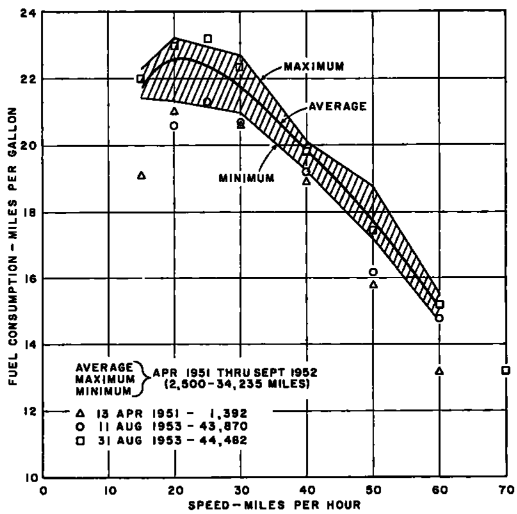

Figure 9. Fuel calibration with burette of 1951 Pontiac Six Sedan on 1-mile level section in third gear for various sustained speeds.

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

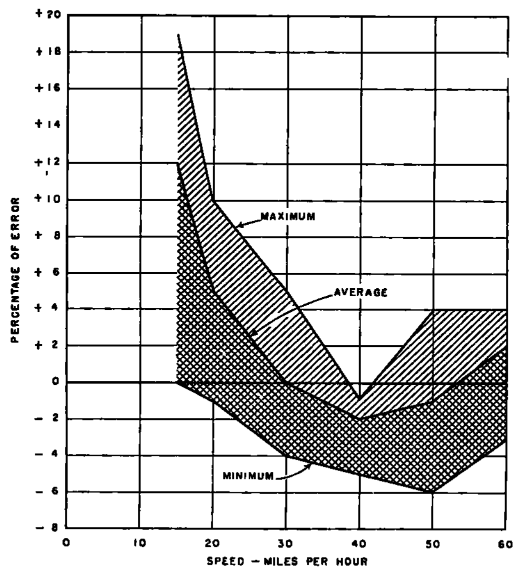

Figure 10. Calibration of fuel meter with burette on 1-mile level section for various sustained speeds during period April 1951 through April 1952.

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.

Test Car Specifications

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:
1st ------- 2.67 to 1
2nd ------ 1.66 to 1
3rd ------ 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 0-3 ft/sec[2]	Percent time over 3 ft/sec[2]	Max deceleration			
	miles	ft/100 ft			mph	mph	mpg	percent	percent	ft/sec[2]	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	—	—	—	—	—	—
	[6] 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]	33 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]	28 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.

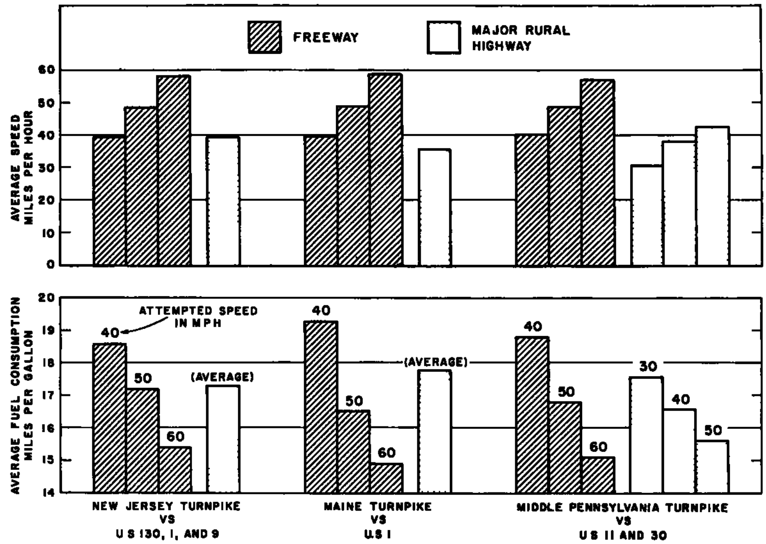

Figure 11. Fuel consumption and speed on freeways compared with that on parallel major rural highways.

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

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

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

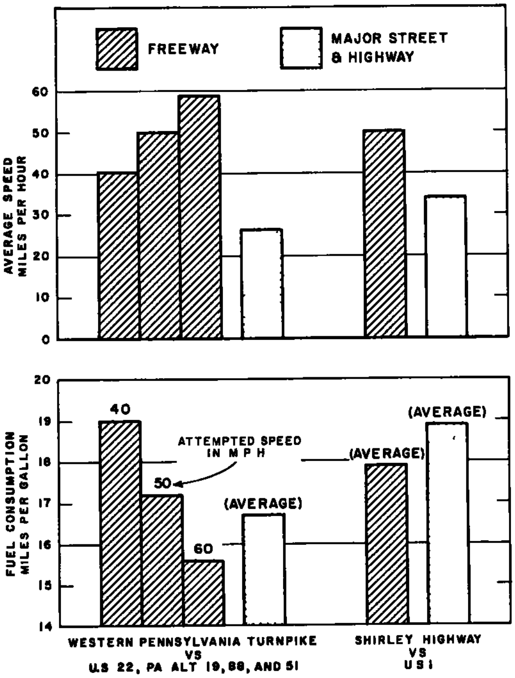

Figure 12. Fuel consumption and speed on freeways compared with that on parallel major streets and highways with a sizeable percentage of mileage in urban areas.

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

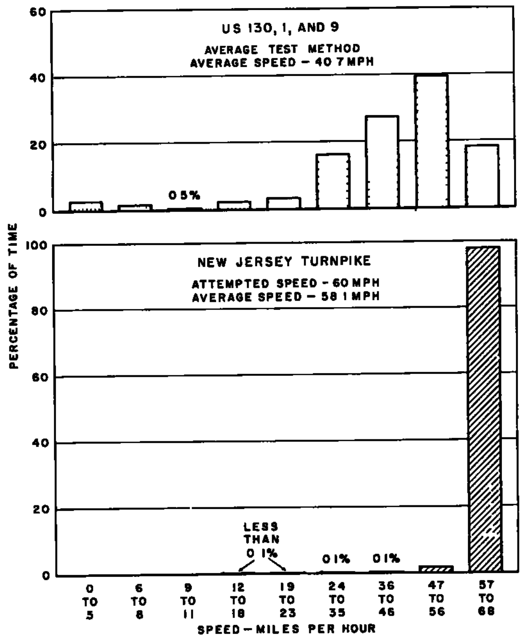

Figure 13. Time distribution by speed groups for New Jersey Turnpike and parallel major highway.

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.

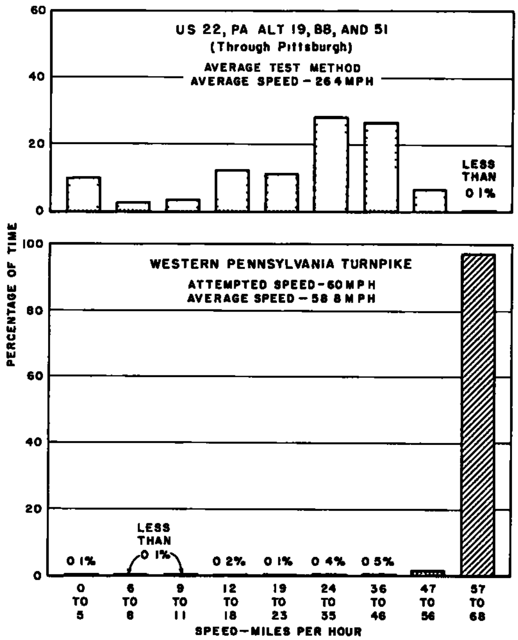

Figure 14. Time distribution by speed groups for Pennsylvania Turnpike and parallel major highway.

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

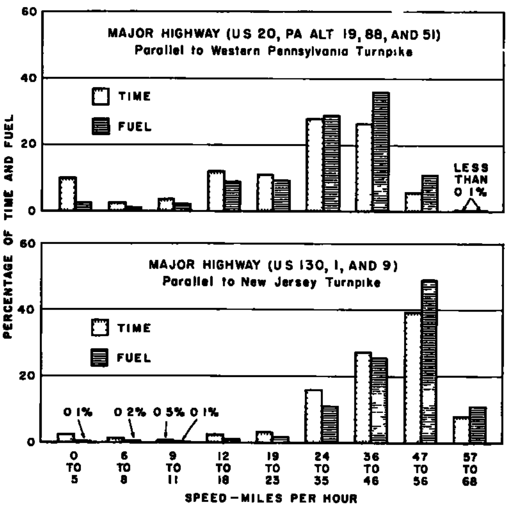

Figure 15. Comparison between time and fuel distribution by speed groups for major highways parallel to New Jersey Turnpike and western Pennsylvania Turnpike.

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.

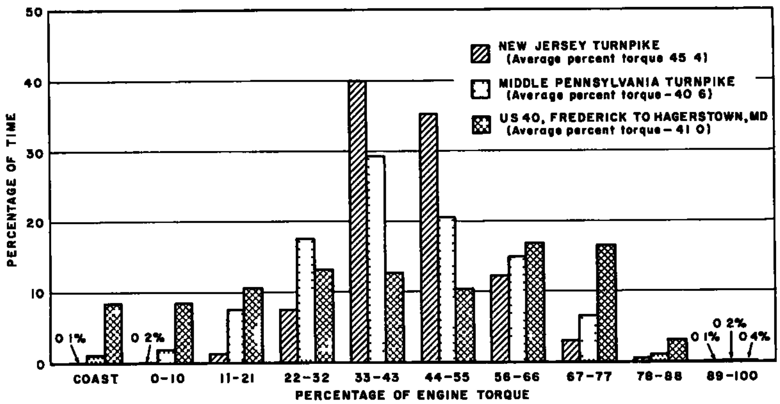

Figure 16. Time distribution by percent engine torque compared for attempted speed of 60 mph. on three test routes with different profile characteristics.

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-

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.

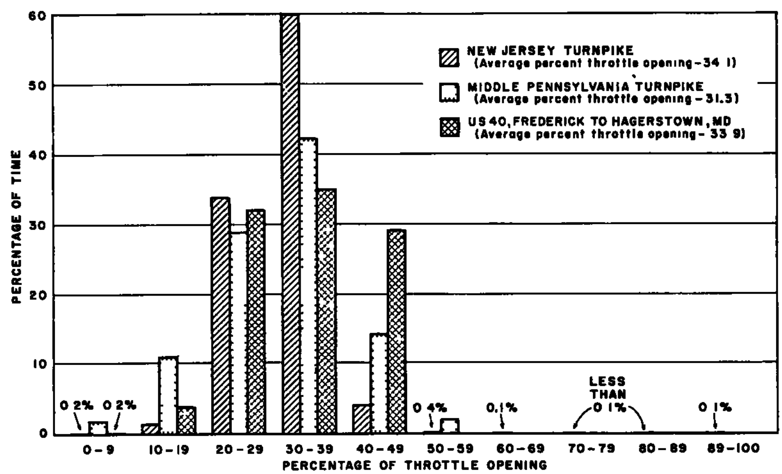

Figure 17. Time distribution by percent throttle opening compared for attempted speed of 60 mph. on three test routes with different profile characteristics.

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.

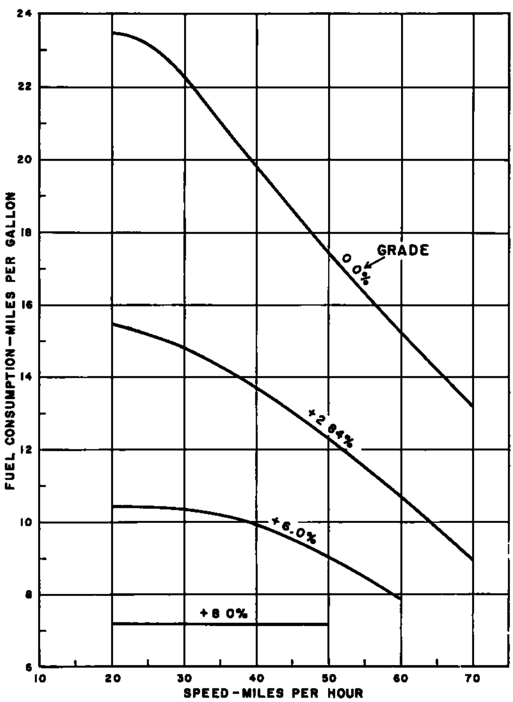

Figure 18. Fuel consumption on ascending uniform grades at sustained speeds.

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

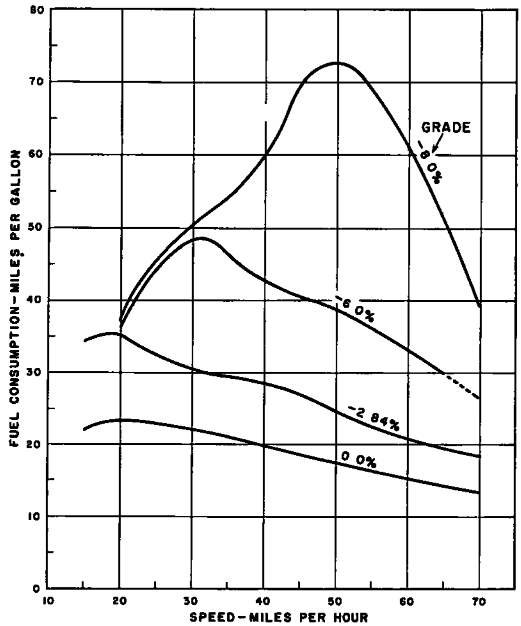

Figure 19. Fuel consumption on descending uniform grades at sustained speeds.

traffic were expedited, as it would be reasonable to assume, it appeared that the purpose of the installation had been accomplished within reasonable limits.

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

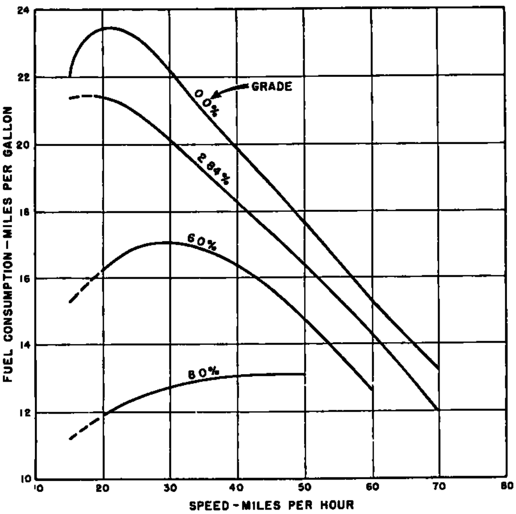

Figure 20. Composite fuel consumption on ascending and descending uniform grades at sustained speeds.

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.

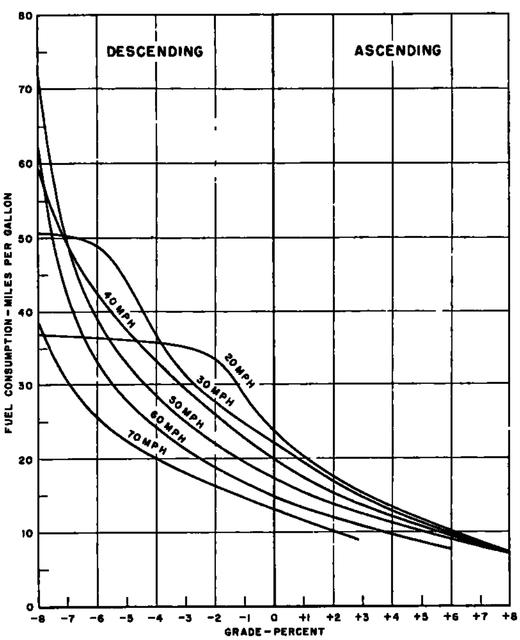

Figure 21. Directional fuel consumption for various sustained speeds as related to gradient.

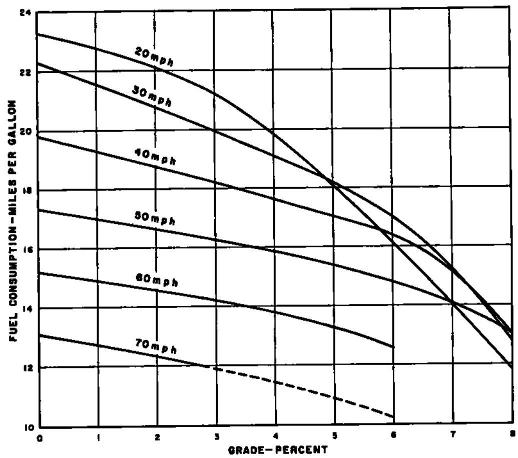

Figure 22. Composite fuel consumption in terms of miles per gallon for various sustained speeds related to gradient.

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

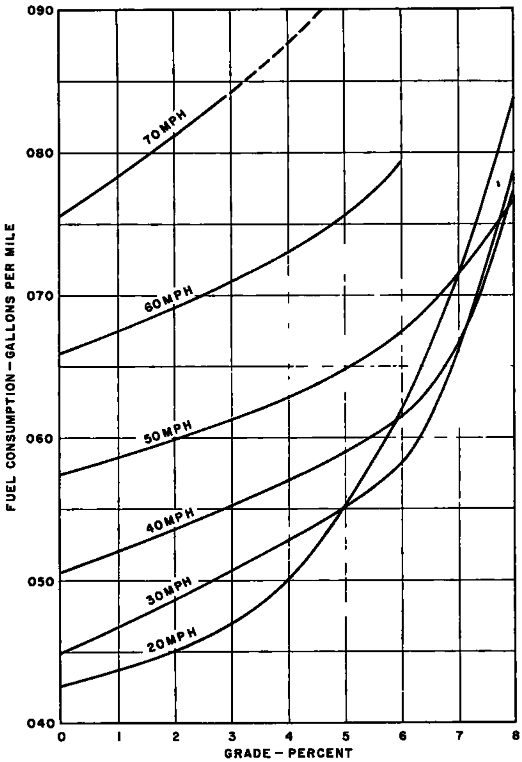

Figure 23. Composite fuel consumption in terms of gallons per mile for various sustained speeds as related to gradient.

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

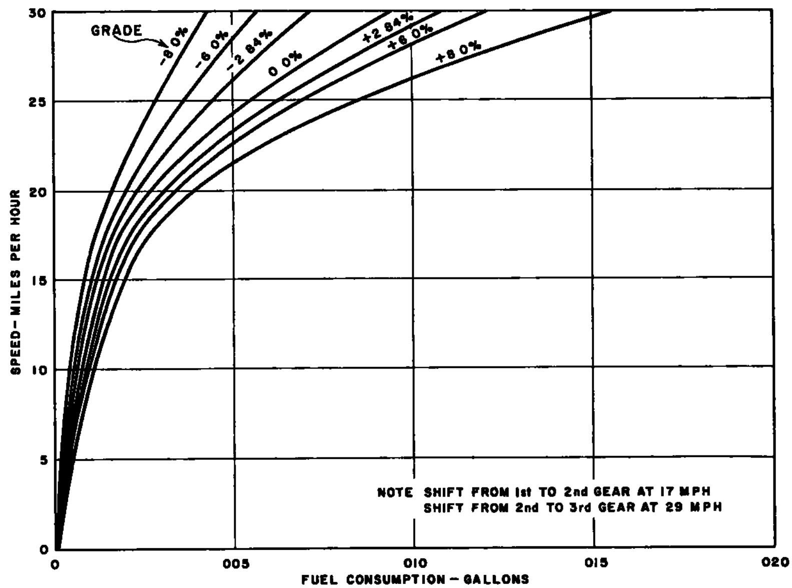

Figure 24. Fuel required to accelerate with full throttle through all transmission gears from a standing start to 30 mph. on various upgrades and downgrades.

30 mph., and in Figure 27 for accelerating in third gear from 20 mph. to the highest practicable speed. For example, to obtain

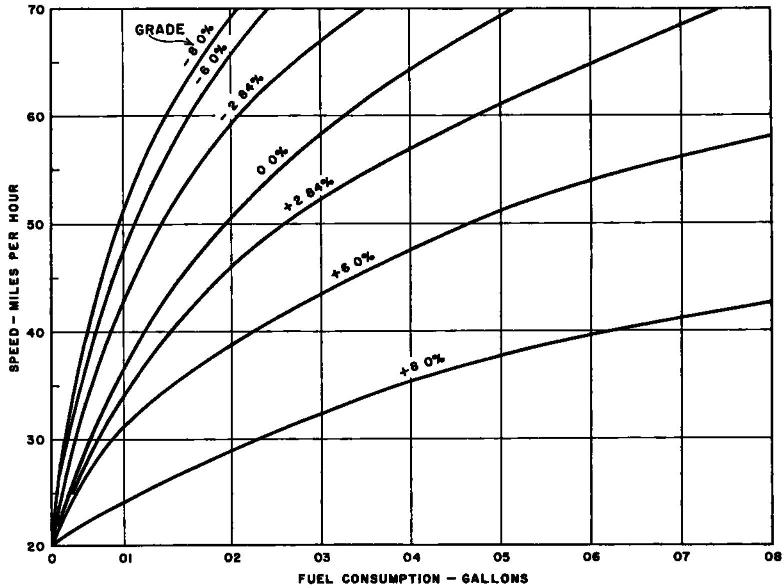

Figure 25. Fuel required to accelerate with full throttle in third gear from 20 mph. to higher speeds on various upgrades and downgrades.

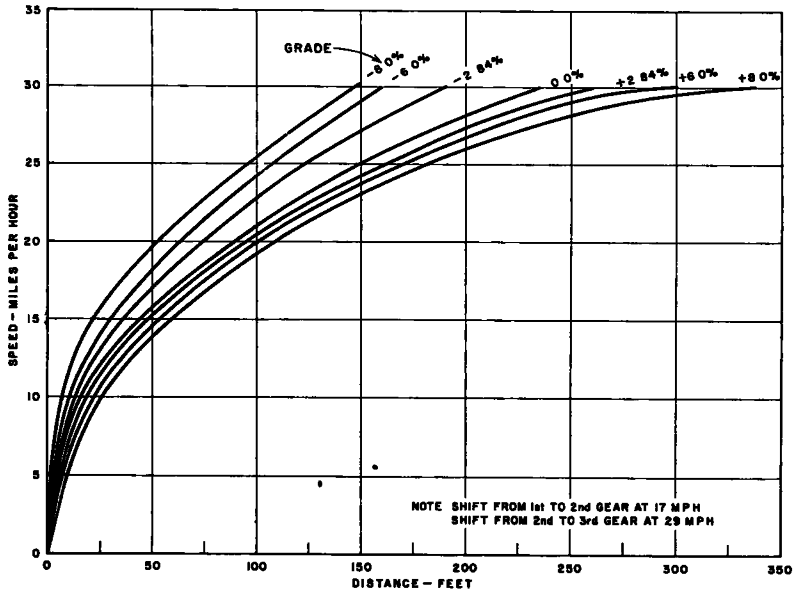

Figure 26. Distance required to accelerate with full throttle through all transmission gears from a standing start to 30 mph. on various upgrades and downgrades.

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

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: 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
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-

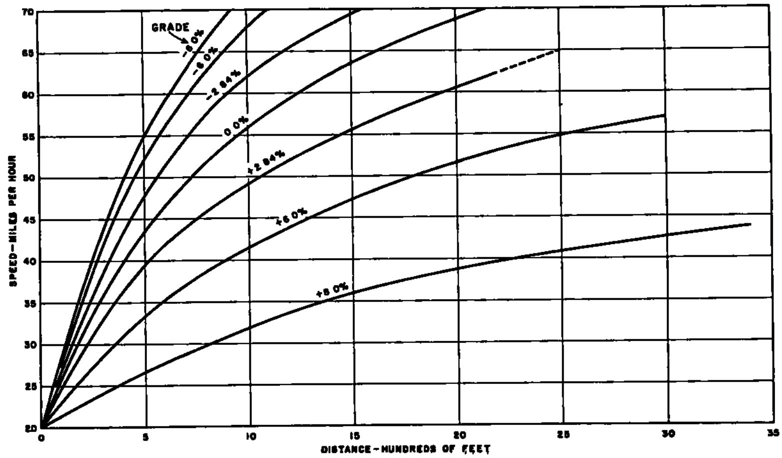

FIGURE
Figure 27. Distance required to accelerate with full throttle in third gear from 20 mph. to higher speeds on various upgrades and downgrades.

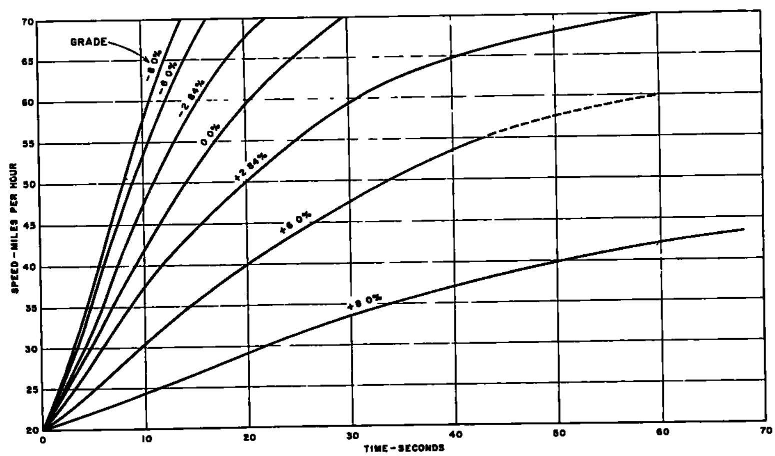

Figure 28. Time required to accelerate with full throttle in third gear from 20 mph. to higher speeds on various upgrades and downgrades.

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: Percent time 0-3 ft/sec²	Braking: Percent time over 3 ft/sec²	Braking: Max. deceleration	Braking: Time factor	Average engine torque
	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.

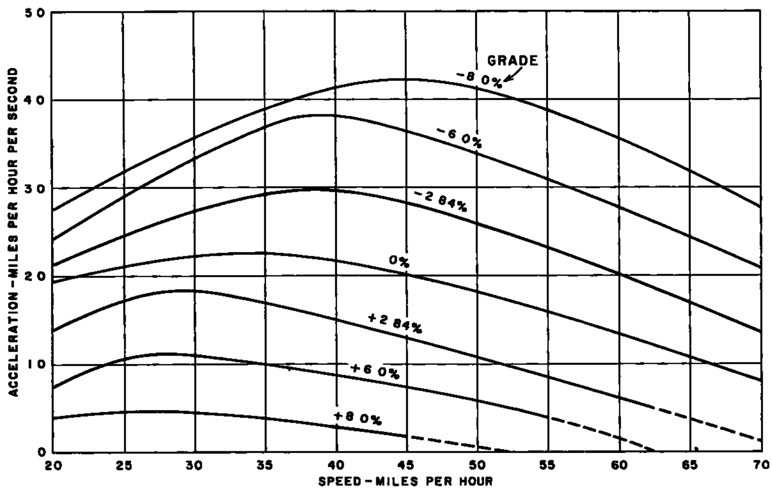

Figure 29. Average instantaneous acceleration rates at various speeds operating in third gear on various upgrades and downgrades.

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

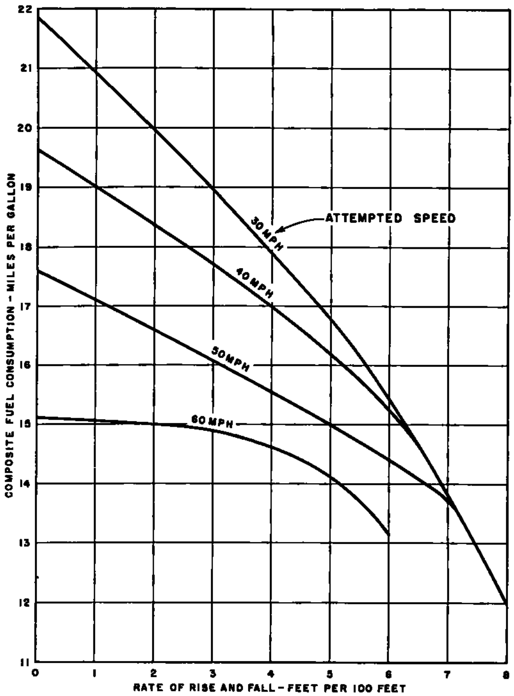

Figure 30. Relation between fuel consumption and the rate of rise and fall.

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.)

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.

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

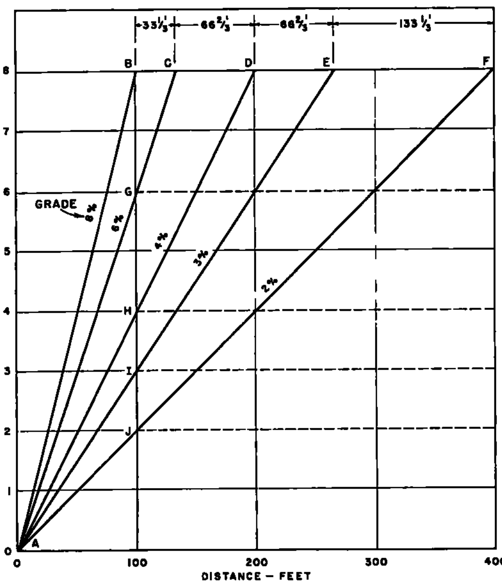

Figure 31. Example for determining savings in fuel consumption by two typical methods of grade reduction.

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	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	98 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] Speed	Posted speed limits [a] Fuel	50 mph.[b] Speed	50 mph.[b] Fuel	40 mph. Speed	40 mph. Fuel	30 mph Speed	30 mph 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.

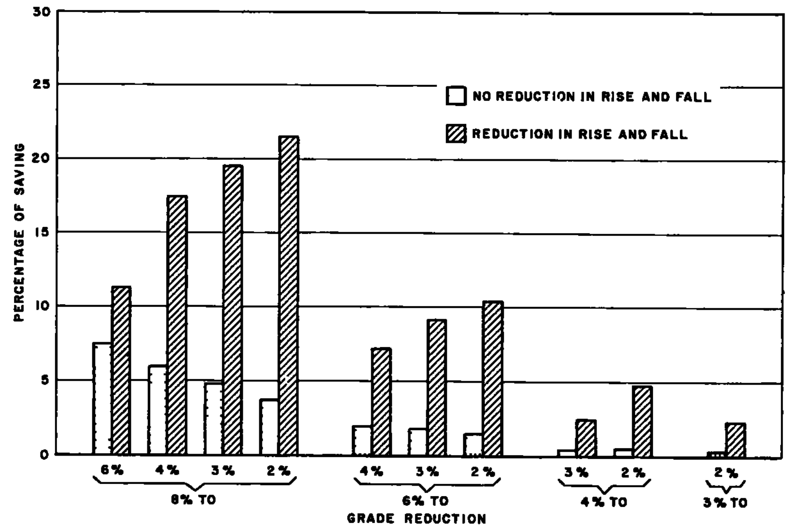

Figure 32. Savings in fuel consumption resulting by two methods of grade production for a sustained speed of 50 mph.

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

ROY H. FIELDING and THOMAS E. YOUNG, Assistant Engineers
Division of Traffic Engineering, City of Cincinnati

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.