Some Measurable Qualities of Traffic Service Influenced by Freeways

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Data is evaluated on travel time and fuel consumption, not a frequent or easily obtainable measurement. In addition, traffic volume relief is presented for one study area to reflect non-user benefits in the form of accessibility and also to present an insight into significant changes in travel time and fuel consumption.

The first portion of the report presents the characteristics of benefits in the form of travel time, overall speed, delay, fuel consumption, distance, and volume for freeway bypass routes as compared to the older business routes.

The rest of the report analyzes the effect on travel time and fuel consumption of speed of operation and traffic volume. The economics of movement of vehicles at various speeds is also investigated to establish the most efficient speed on the basis of values of travel time and fuel.

The results of the freeway bypass evaluation show that the economic benefit as a result of the construction of a freeway will always be a positive quantity on the basis of travel time savings, even in cases where the freeway distance is 12 percent greater than the older business route. However, the fuel consumption may be negative depending on route distances, character of the speed change and the type of vehicle. By combining these two economic benefits the optimum economic speed of operation is indicated.

•RESEARCH on the operating characteristics of vehicles, particularly fuel consumption and travel time, has been conducted at the University of Washington for the past 5 yr. In the summer of 1962, the University of Washington research group entered into a contract with the Washington State Highway Commission and the U. S. Department of Commerce Bureau of Public Roads for measuring the fuel consumption, travel time, and delay experienced on an existing congested primary State highway between the cities of Seattle and Tacoma. Extensive measurements were made for various volume conditions and types of vehicles, ranging from a small compact to a large tractor and semi-trailer combination. This 12.5-mi section of highway has been replaced by a 6-lane freeway, and subsequent measurements of fuel consumption and travel time have been made on the freeway and then again on the old section of the State highway. The primary purpose of the contract is to collect and assemble data on time, fuel, and volume on the existing route and also on routes in the City of Seattle before any segments of the freeway network are completed and open to traffic. These data will provide the "before" portion of a before-and-after study of freeway benefits. The contract also includes a limited "after" study because a 12.8-mi section of freeway between Seattle and Tacoma was opened to traffic during the period of the contract. Preliminary results are presented in this paper for the trip savings by vehicle type.

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In addition, data has been collected on travel time and fuel consumption on freeway sections bypassing the City of Olympia and on the previous State highway routes through the business section of Olympia. This report presents the preliminary results of user benefits of savings in time and fuel consumption for a standard passenger car trip.

It is the intent in the first portion of the paper not to present new techniques of data collection but to provide factual information on the magnitude of benefits realized by the improvement of existing congested arterial routes in comparison to the operation of free-flowing traffic on freeways.

The latter portion of the paper attempts to correlate meaningful measurements important in the statistical analysis of field measurements. In addition, a preliminary investigation is presented to stimulate additional interest in a more precise evaluation of items directly related to the quality of traffic service.

TEST ROUTE DESCRIPTION

The research contract required the collection of data on six routes on the Olympia test site, two on the Seattle-Tacoma site and four on the Seattle test site. This report utilizes the first two test sites.

Olympia Test Site

On Dec. 12, 1958, the Washington State Highway Commission opened a section of US 99 freeway bypassing the City of Olympia. In addition, a section of US 101 freeway, bypassing Olympia to the west, was also opened to traffic. These two freeway sections resulted in bypasses in three general directions, i.e., south to east and east to south for US 99, south to west and west to south for US 101, and east to west and west to east for US 410. The study routes for these bypass and business routes are shown in Figures 1 and 1A. Figure 1 shows the data checkpoints for the 1958 before study and the 1959 after study. Figure 1A shows the 1963 checkpoints for the freeway and business routes.

Seattle-Tacoma Test Site

The first segment of the freeway between Tacoma and Seattle to be opened to traffic was the portion from the Port of Tacoma road to Midway at SSH-5A. This freeway route is 12.846 mi in length for Seattle-bound traffic and 12.746 mi for Tacoma-bound traffic. Figure 2 shows the general vicinity of the test site location, which also includes the old highway route of the primary State highway consisting of a 4-lane undivided highway in some sections and channelized for turn movements and access controls at other locations. The old route was equipped with fully actuated traffic signals at four locations.

TEST VEHICLE DESCRIPTION

The Olympia study in March of 1963 utilized a 1963 standard V8 4-door sedan. The vehicle is test unit 6 and nearly identical with test unit 2 (Fig. 3).

The Seattle-Tacoma routes utilized five different vehicle types, including a 1962 U. S. compact 4-door sedan, a 1962 standard V8 4-door sedan, a 1962 half-ton 6-cylinder pickup truck, a 1955 Diesel 3-S2, and a 1962 single unit truck with dual tires (Fig. 3). Detailed descriptions of the test vehicles are contained in Appendix A.

The after study on the Tacoma-Seattle route was conducted in December 1962 and utilized test units 1 and 2 (compact and standard passenger car, respectively).

DESCRIPTION OF DATA COLLECTION

This report utilizes the data collected on the US 99 Olympia bypass, which is of major significance from the standpoint of relief to traffic congestion for graphical presentation. Preliminary results are also tabulated for the other routes. The Washington State Highway Commission in November and December 1958 collected travel time and fuel consumption on the existing city business routes and in March 1959 collected after

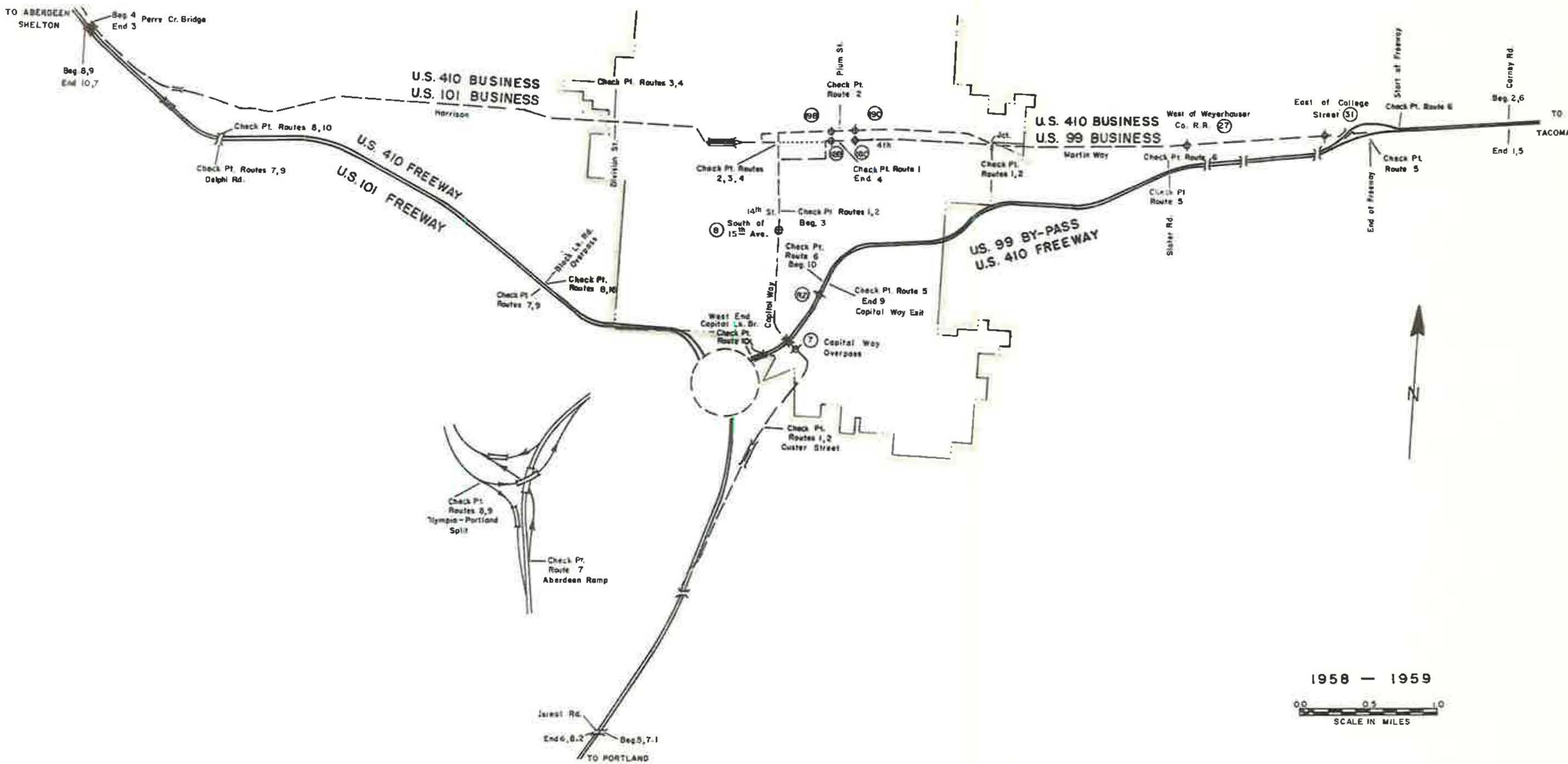


Figure 1. Olympia study routes, 1958-1959.

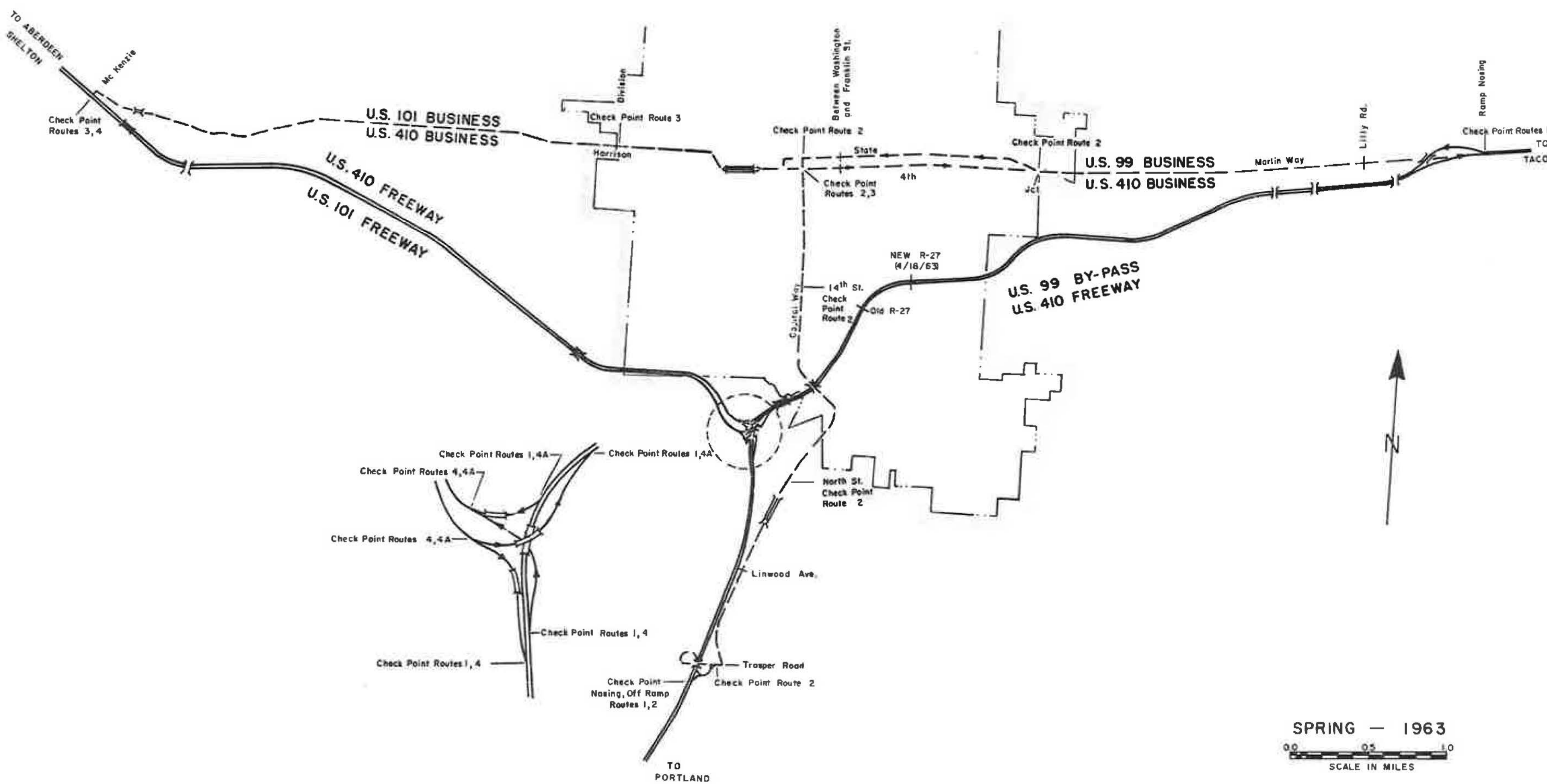


Figure 1A. Olympia study routes, Spring 1963.

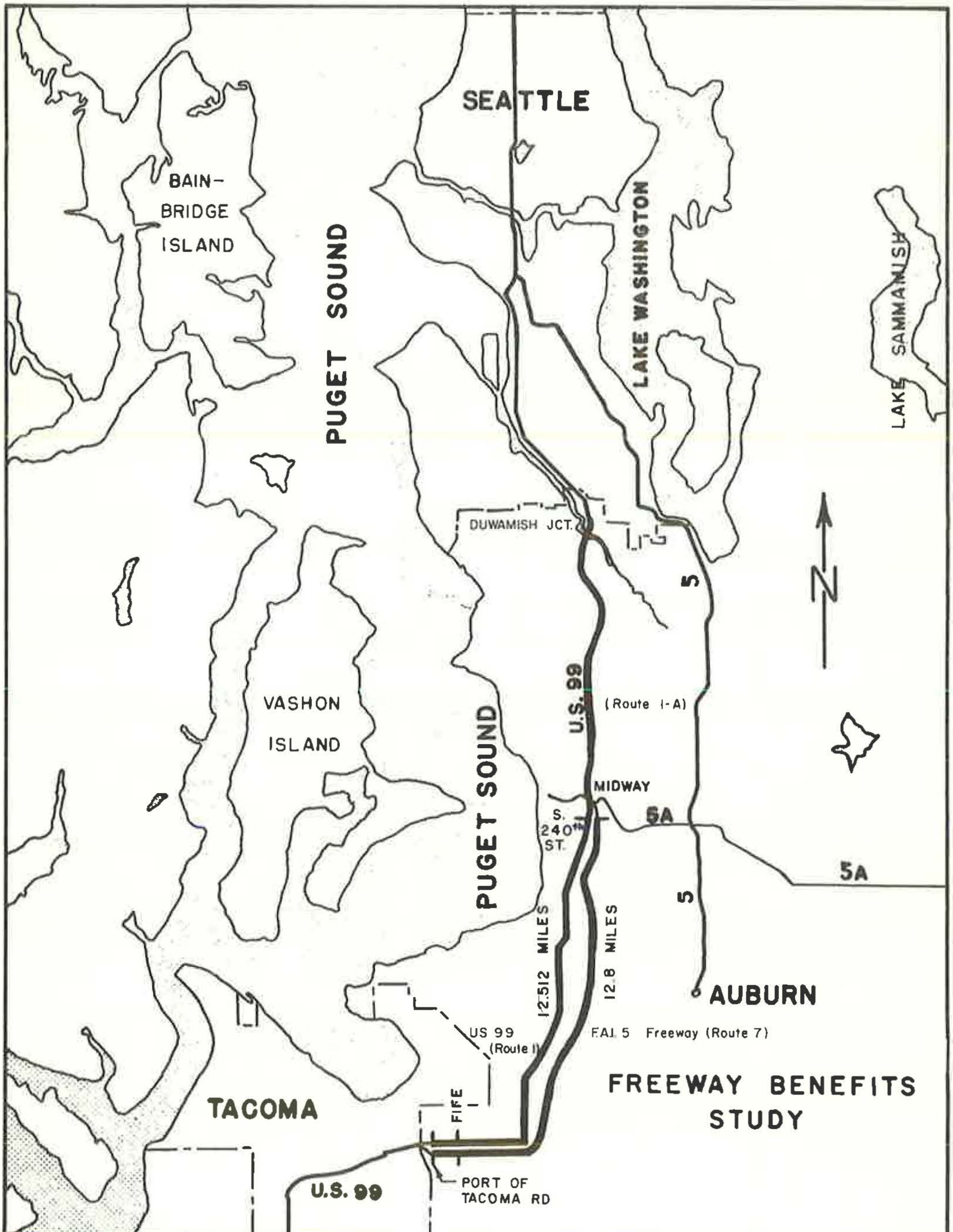


Figure 2. Vicinity map, US 99 test section.

Test Unit 1- 1962 Compact 4-Door Sedan.

Test Unit 4- 1955 Diesel 3-S2

Test Unit 2- 1962 Standard V-8 4- Door Sedan.

Test Unit 5- 1962 Single Unit Truck With Dual Rear Tires.

Test Unit 3 – 1962 Half Ton 6 Cylinder Pick Up.

Test Unit 6 – 1963 Standard V-8 4-Door Sedan.

Figure 3. Test vehicles.

data on the business and freeway routes. Due to the limitations in the fuel metering device used on these earlier studies the State Highway Commission requested the University research group to re-evaluate the fuel consumption and travel time of vehicles operating on the business routes vs those traveling on the freeway bypasses. These data were collected in March 1963 and is the primary source of information utilized in this report.

On the Seattle-Tacoma test site, fuel consumption, travel time and delay were observed on the old route under a wide variety of traffic volume conditions and on weekdays as well as weekends.

The unopened freeway route was utilized for calibrating the fuel consumption of the test vehicles for a range of constant speeds. This calibration is necessary for future comparison with similar vehicles to be utilized during the after portion of the study. Data were not collected using the average car method on the freeway route, because the speed of operation was at the discretion of the driver, and was not affected by traffic volume. However, a license check method was used to determine the actual travel time (overall speed) of various types of vehicles (Appendix B). This speed data can be used with the vehicle calibration curves to determine the fuel consumption. Data was again collected on the old route to evaluate the traffic service relief.

Fuel Consumption

Fuel consumption was measured by two methods in these series of tests. The fuel meter model FM 200 was utilized for measuring the fuel consumption of the passenger cars, whereas the burette board method was utilized on the trucks. Although the FM 200 meter is considered to be more accurate for instantaneous readings enroute, only one such meter was available. The burette boards were used so that data from two vehicles could be recorded simultaneously. Figure 4 shows typical installations of the FM 200 meter and the burette board and Figure 5 shows the FM 201 digital counter unit of the FM 200 fuel meter. More details of these metering devices are contained in Appendix C.

Both fuel metering devices utilized a fuel temperature gage for making a temperature correction to a standard 68 F. A calibration constant of 1529.3 counts per gal, valid for a wide range of flow rates, for converting the counts to gallons was determined in the laboratory for the FM 200 meter. The fuel consumption recorded by the burette boards was converted from milliliters to gallons.

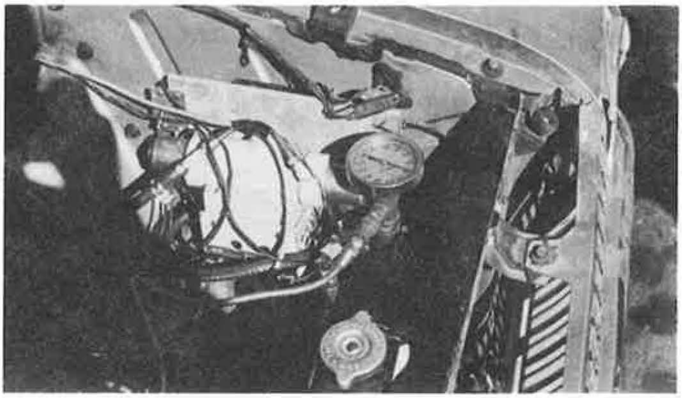
The frequency of recording the fuel consumption enroute is predicated on the volume of fuel required to traverse the section so that sufficient quantity is observed to obtain reliable accuracy. The frequency of fuel observations was generally less than the travel time observations.

Travel Time Measurements

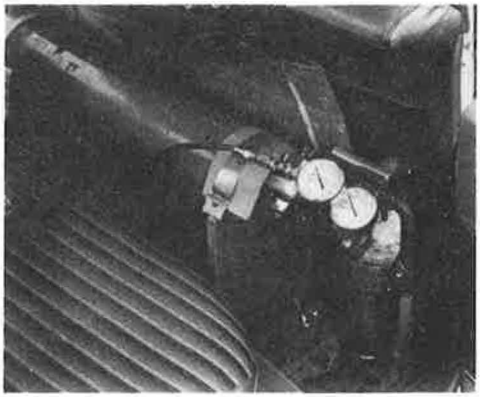
Two stop watches were used to measure the travel time along the route while utilizing the FM 200 fuel meter. These watches could be read to 0.01 min. One watch was stopped while the other was simultaneously started so that incremental times between checkpoints could be determined (Fig. 5). In using the burette board for measuring fuel consumption it was necessary to record accumulated travel time because the observer was occupied with switching the valves on the fuel meter at the checkpoint. An additional stop watch was utilized for measuring the delay time (any time the vehicle was stopped or traveling at less than 5 mph). As an overall check the driver operated a total route stop watch which was started at the beginning of a test route and stopped at the end for comparing with the accumulated observed travel time (Fig. 5, Appendix D).

Distance Measurements

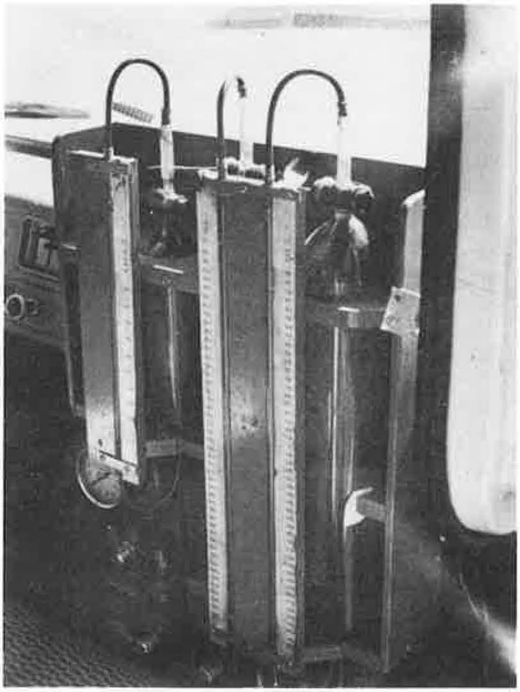
Routes on the Olympia test site were measured in 0.01 mi using a calibrated State highway department vehicle. All other routes were measured to 0.001 of a mile with a calibrated fifth wheel attachment (Fig. 5).



Typical FM 200 Fuel Meter Installation

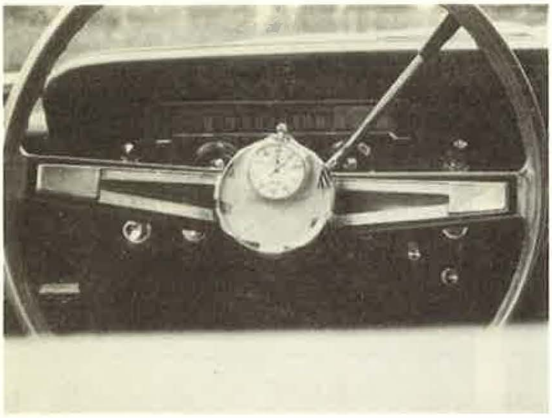


Typical Nitrogen Bottle Installation - Used With FM 200.



Typical Burette Installation.

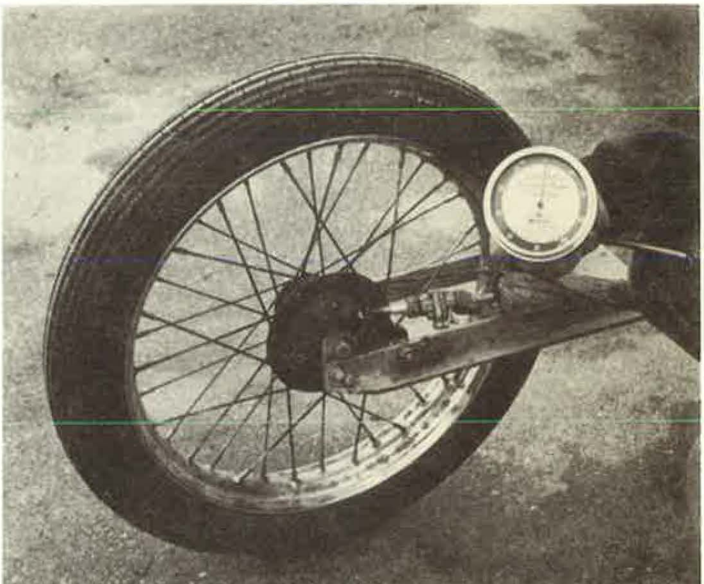
Figure 4. Fuel meter installations.



Typical Driver's Watch Installation.

Observers Watches on Data Recording Board. Note FM 201 Digital Counter.

Typical Fifth Wheel Installation.



Fifth Wheel With Survey Odometer Head.

Figure 5. Watch and fifth wheel installations.

Traffic Volume

Traffic volume data was recorded by the Highway Planning Division for both test sites. The data collected in 1958, 1959 and 1963 were not always taken at identical locations; therefore, there can be no direct comparison of the traffic volume section by section along the routes. This lack of control of the data has made it more difficult to make a complete evaluation of total benefits and, therefore, those presented in this report are for a single vehicle trip.

In general, the traffic volume was recorded on automatic recording traffic counters by 15 min intervals. The data for the Seattle-Tacoma freeway route is more complete and, therefore, is utilized in the detailed analysis of the relationship of volume to the other variables.

ANALYSIS OF THE DATA

All data collected, including fuel in counts or milliliters, travel time in minutes and traffic volume as recorded by the automatic recording counters, were processed on punch cards for electronic computer calculations. A computer program was prepared for making the necessary corrections to the measured fuel to adjust for fuel temperature and for calibration (Appendix C). The program required the distance between fuel checkpoints so that calculations could be tabulated not only for the total fuel in gallons, but also the gallons per mile and the miles per gallon. The program converted the travel time into overall speed, running speed, number of delays and delay time.

The traffic volume data for the Seattle-Tacoma test site were keypunched directly from recording counter tapes and a program was written to convert accumulated volumes to 15-min incremental volumes. The program was expanded to include the 24-hr total and also any comments indicating possible sources of error that had been noted on the counter tapes.

The two computer programs have not been interrelated due to some deficiencies in volume data resulting from counter malfunctions. Volume data were extracted manually from computer output for analysis or data plotting of fuel consumption, speed or travel time vs volume.

Route Savings in Fuel, Travel Time and Distance

The computer calculation of the fuel and travel time data was prepared for printout in such a way that each section of each route could be tabulated separately. The fuel and travel time consumed from checkpoint to checkpoint for the business routes were averaged and then weighted for traffic volume during the peak periods and off-peak periods and the accumulated fuel and travel time were calculated and plotted for the business and freeway routes bypassing Olympia. In addition, this plot also represents any savings in distance which should be considered in conjunction with time and fuel consumption savings. Figures 6 and 7 represent the directional savings derived from the US 99 bypass. The fuel and travel time savings resulting from the research were converted to economic benefits using values of time and fuel recommended by AASHO (1). These results are given in Table 1 for all three bypass routes.

An analysis of the savings and economic benefits of four of the five vehicle types traveling on the Seattle-Tacoma Freeway route is presented in Table 2. The values of fuel and travel time are considered accurate because the sample size varies in nearly the same proportion as the traffic volume and, therefore, a simple arithmetic average value can be calculated. The freeway average overall speed was obtained from Appendix B. Figures 8 and 9 were utilized for obtaining the directional fuel consumption consistent with the overall speed converted from the license check travel time. The comparison results in an economic benefit per round trip for a passenger car of -\$0.0333 for fuel and +\$0.2042 for travel time or a total benefit of +\$0.1709.

The total of travel time and fuel economic benefits range from +\$0.0578 for the pick-up to +\$0.2705 for the diesel tractor and trailer for a northbound trip.

An analysis was also made of the benefits derived by those still using the old route. Data collected with the standard passenger car reveal an average fuel consumption of

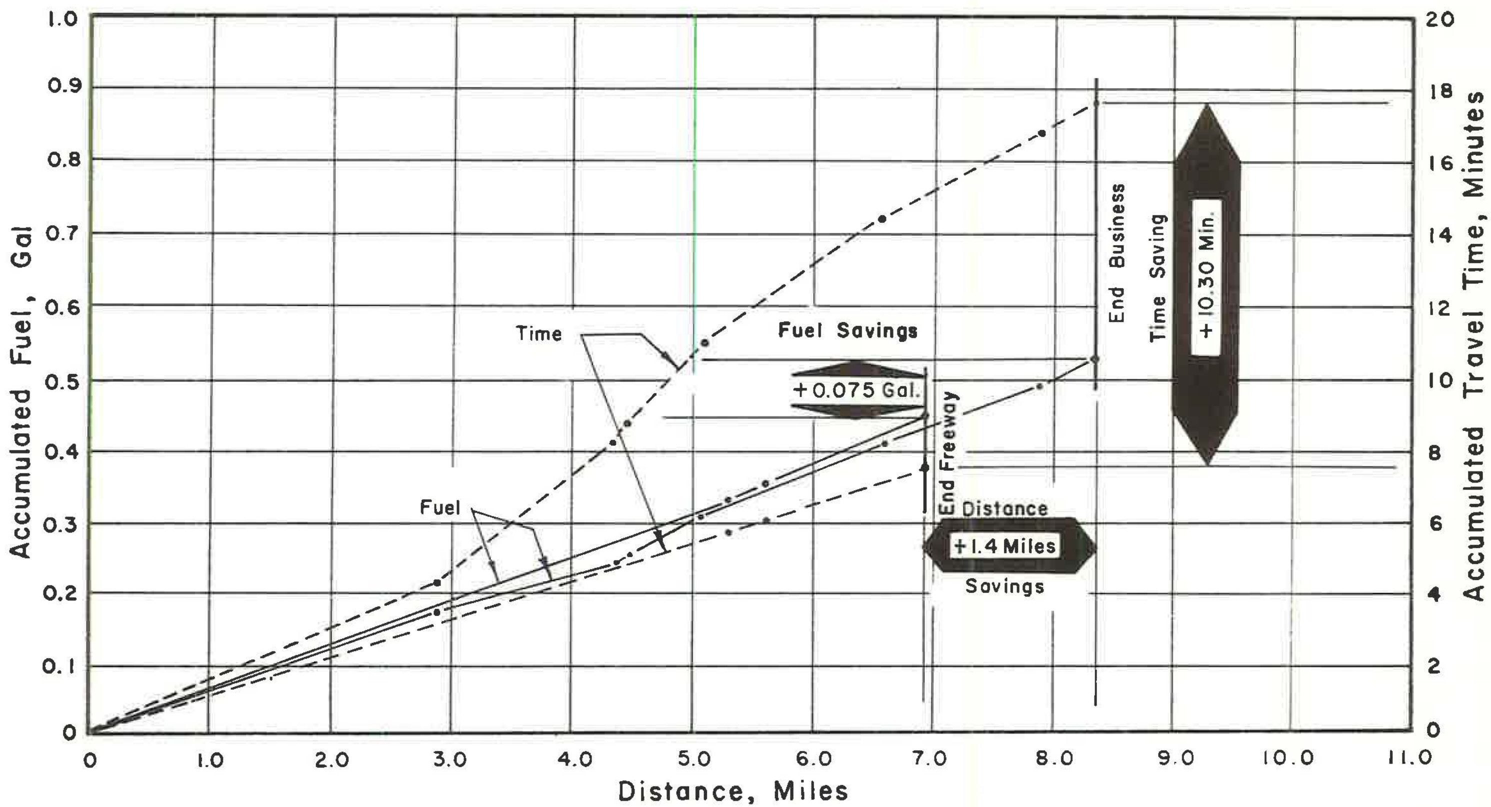


Figure 6. Accumulated fuel and travel time in 1963 by business and freeway routes for US 99 (E-S), Olympia, for standard passenger car (AWD values).

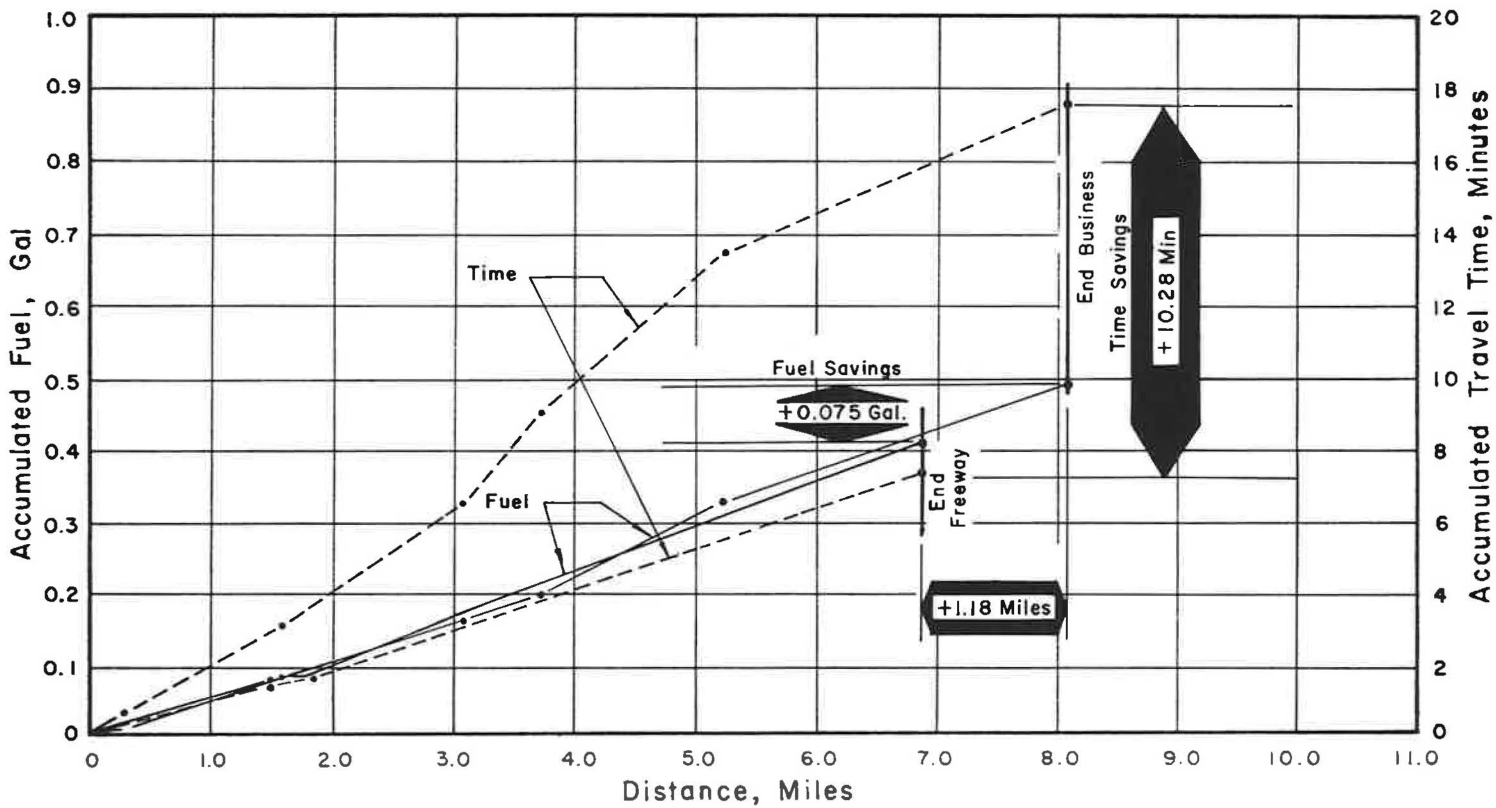


Figure 7. Accumulated fuel and travel time in 1963 by business and freeway routes for US 99 (S-E), Olympia, for standard passenger car (AWD values).

TABLE 1

ECONOMIC BENEFIT FOR A STANDARD PASSENGER CAR: OLYMPIA BYPASS ANAYLSIS DURING OLYMPIA FREEWAY OPERATION

Routes	Business Routes			Freeway			Savings			Economic Benefits[a] ($)		
	Fuel (gal)	Travel Time (min)	Distance (mi)	Fuel (gal)	Travel Time (min)	Distance (mi)	Fuel (gal)	Travel Time (min)	Distance (mi)	Fuel	Travel Time	Total
US 99, E-S	0.5172	17.7293	8.35	0.442	7.43	6.95	+0.0752	+10.2993	+1.4	+0.0241	+0.2657	+0.2898
US 99, S-E	0.4870	17.5813	8.05	0.412	7.30	6.87	0.075	10.28	+1.18	+0.0240	+0.2652	+0.2892
US 101, W-S	0.568	17.48	8.47	0.412	6.93	6.36	+0.156	+10.55	+2.11	+0.0499	+0.2722	+0.3221
US 101, S-W	0.512	18.02	8.35	0.372	7.15	6.41	+0.140	+10.87	+1.94	+0.0448	+0.2804	+0.3252
US 410, W-E	0.587	17.11	10.08	0.628	10.90	8.94	-0.041	+ 6.21	-1.14	-0.0131	+0.1602	+0.1471
US 410, E-W	0.544	16.58	8.99	0.609	11.02	10.06	-0.065	+ 5.56	-1.07	-0.0208	+0.1434	+0.1226

[a]Values based on $0.32 per gal and $0.0258 per min (1).

TABLE 2

ECONOMIC BENEFITS FOR ALL VEHICLES DURING FREEWAY OPERATION[a]

Vehicle Direction	Old Route Before			Freeway			Savings			Economic Benefits ($)[b]		
	Fuel (gal)	Travel Time (min)	Distance (mi)	Fuel (gal)	Travel Time (min)	Distance (mi)	Fuel (gal)	Travel Time (min)	Distance (mi)	Fuel	Travel Time	Total
Veh 2, N. B.	0.795	17.240	12.511	0.859	12.975	12.846	-0.064	4.265	-0.335	-0.0205	0.1100	0.0895
Veh 2, S. B.	0.700	16.730	12.511	0.740	13.080	12.746	-0.040	3.650	-0.235	-0.0128	0.0942	0.0814
Veh 3, N. B.	0.749	17.255	12.511	0.913	12.980	12.846	-0.164	4.275	-0.335	-0.0525	0.1103	0.0578
Veh 3, S. B.	0.647	17.119	12.511	0.813	12.950	12.746	-0.165	4.169	-0.235	-0.0531	0.1076	0.0545
Veh 4, N. B.	2.396	21.395	12.511	2.280	16.670	12.846	+0.116	4.725	-0.335	+0.0342	0.2363	0.2705
Veh 4, S. B.	1.878	20.113	12.511	1.773	15.490	12.746	+0.105	4.623	-0.235	+0.0310	0.2312	0.2622
Veh 5, N. B.	1.482	18.944	12.511	1.908	14.710	12.846	-0.426	4.234	-0.335	-0.1363	0.2117	0.0754
Veh 5, S. B.	1.224	18.392	12.511	1.418	14.735	12.746	-0.194	3.657	-0.235	-0.0621	0.1829	0.1208

[a]On weekdays only.
[b]Data based on values of time for passenger cars, $0.0258 per min (1); for trucks $0.050 per min (from wage scale); gas, $0.32 per gal; diesel fuel, $0.295 per gal.

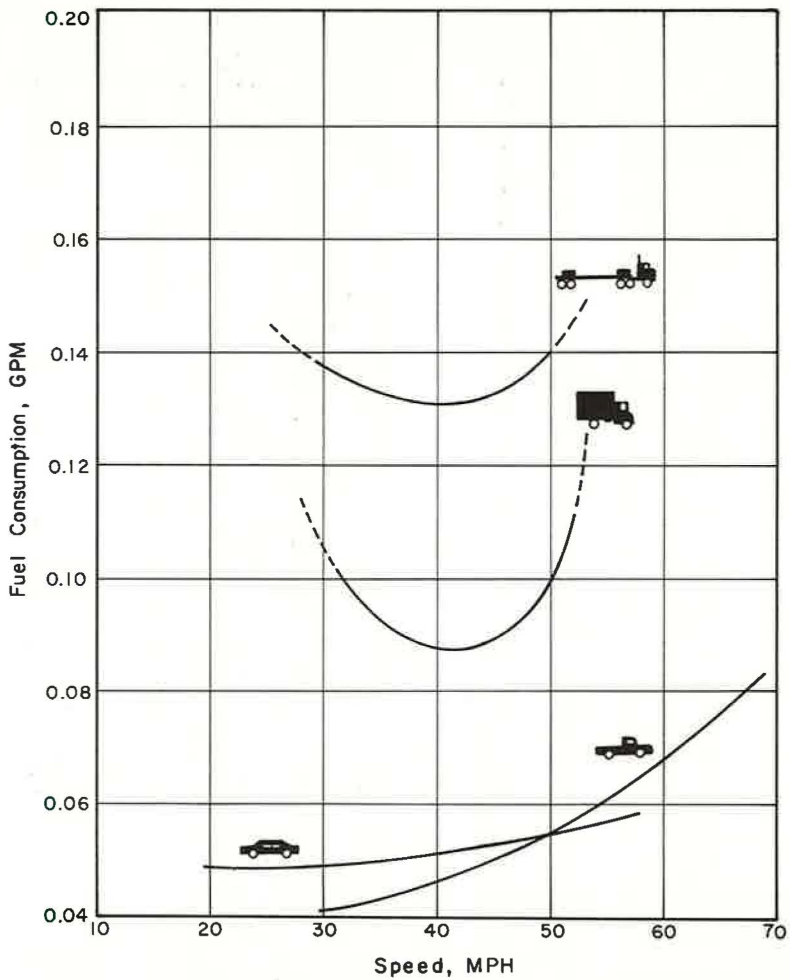


Figure 8. Fuel consumption for various constant speeds on the calibration test section for standard passenger car, pickup, single unit, and tractor and trailer (S.B.).

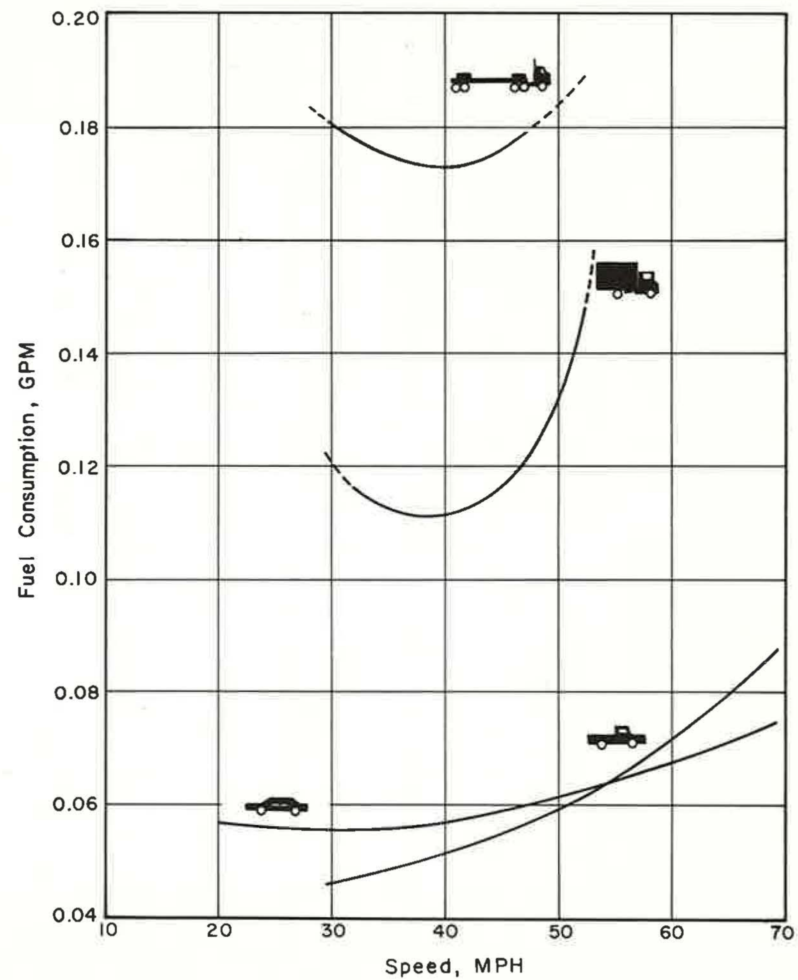


Figure 9. Fuel consumption for various constant speeds on the calibration test section for standard passenger car, pickup, single unit, and tractor and trailer (N.B.).

0.7967 gal N. B. and 0.6941 gal S. B., and an average travel time of 17.926 min N. B. and 16.780 min S. B.. Comparison of these values with those given in Table 2 (Old Route Before) shows a combined economic benefit of +$0.0418 for a round trip. The benefit in travel time would be +$0.0463 and in fuel -$0.0045.

Traffic Volume Adjustment of Observations

Considerable analysis was performed to determine the proper weighting of fuel consistent with traffic volume conditions. In selecting the sample size for making the observations for the Olympia bypass study it was necessary to secure a greater number of observations during peak hour traffic conditions than during the other hours of the day in order to obtain a sample large enough for calculating a statistically accurate average. However, these values could not be summed and a simple average taken, because the size of the sample during the peak hour would determine the amount of weighting of these observations. To establish the need to weight the observations, the following analysis was conducted for the US 99 business route through Olympia:

1. The hourly volume variation at each counter location was reviewed to determine the peak traffic volume period of 1 hr in the morning and 1 hr in the evening.
2. Fuel and travel time values during each of the peak periods and the off-peak time were averaged separately.
3. The three averaged values for fuel and travel time were multiplied by the percent of volume traveling during the corresponding period in each section along the route. The sum of these three products represents the true average daily fuel or travel time consumption for each section along the route. The total of these values represents the true volume weighted weekday average for the route (Appendix E).
4. The preceding method is used for each of the sections of the route and is plotted as a horizontal line representing the true volume weighted average value for each section and the route (Fig. 10).
5. The average of all recorded values, regardless of the time of day, was then calculated for each section and plotted as a percent of the true volume weighted average value (Fig. 10). This method can be considered an average weighted in relation to the sample size during the three time periods. The possible error in the average may be as great as +3.947 percent for one section, but the route error would be only +1.121 percent. Although the error is small the true method is recommended unless the sample size is proportionate to the traffic volume, as in the case of the Seattle-Tacoma test section. The volume weighting method has been used only for the US 99 Olympia bypass route.

An unweighted value might be considered to be the simple average of all runs made in one day (Fig. 10).

The variation of travel time and fuel values with corresponding volumes throughout the day are presented in Figure 11.

Overall Speed as Level of Service

Overall speed has been utilized in the past, and is verified in this report, as a reliable method of portraying a level of service along a route. The overall speed is calculated from the travel time but generally travel time is not utilized as an indicator of the point-to-point level of service. By utilizing overall speed, all unequal length sections along a route are standardized for comparison. The overall speeds for the US 99 Olympia bypass and business routes for 1963 are shown in Figures 12 and 13. In addition, the level of service by overall speed is also indicated in Figures 14 and 15 for the US 99 business route in 1958 before, and 1959 immediately after on both the business and freeway routes, utilizing different checkpoints than the 1963 study.

Delay as Level of Service

In utilizing overall speed as a level of service it is a misinterpretation to consider that a drop in the overall speed is directly associated with a reduction in level of ser-

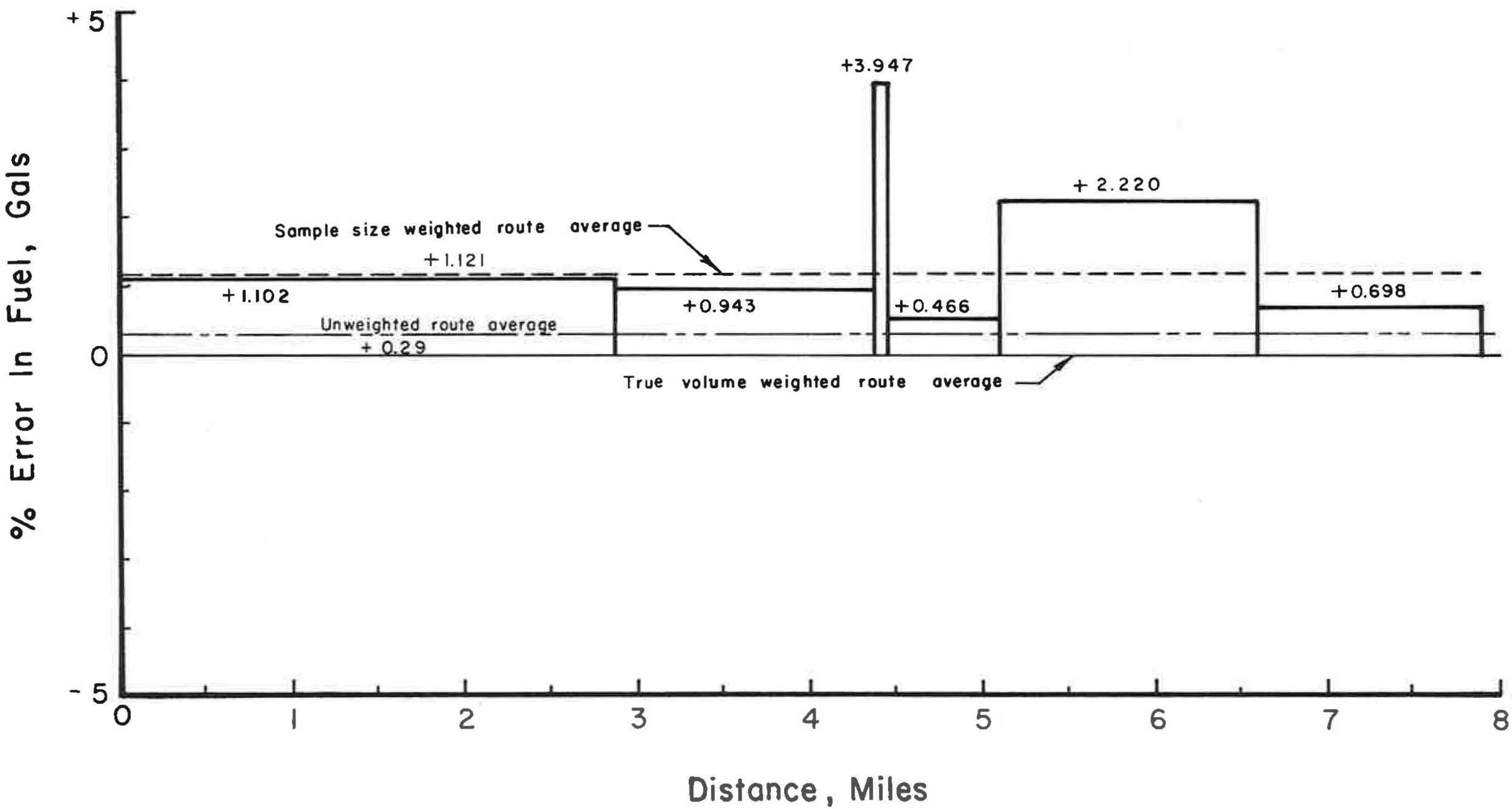


Figure 10. Possible error in percent using sample size weighted average fuel values vs volume weighted average for US 99 business route, Olympia (E-S).

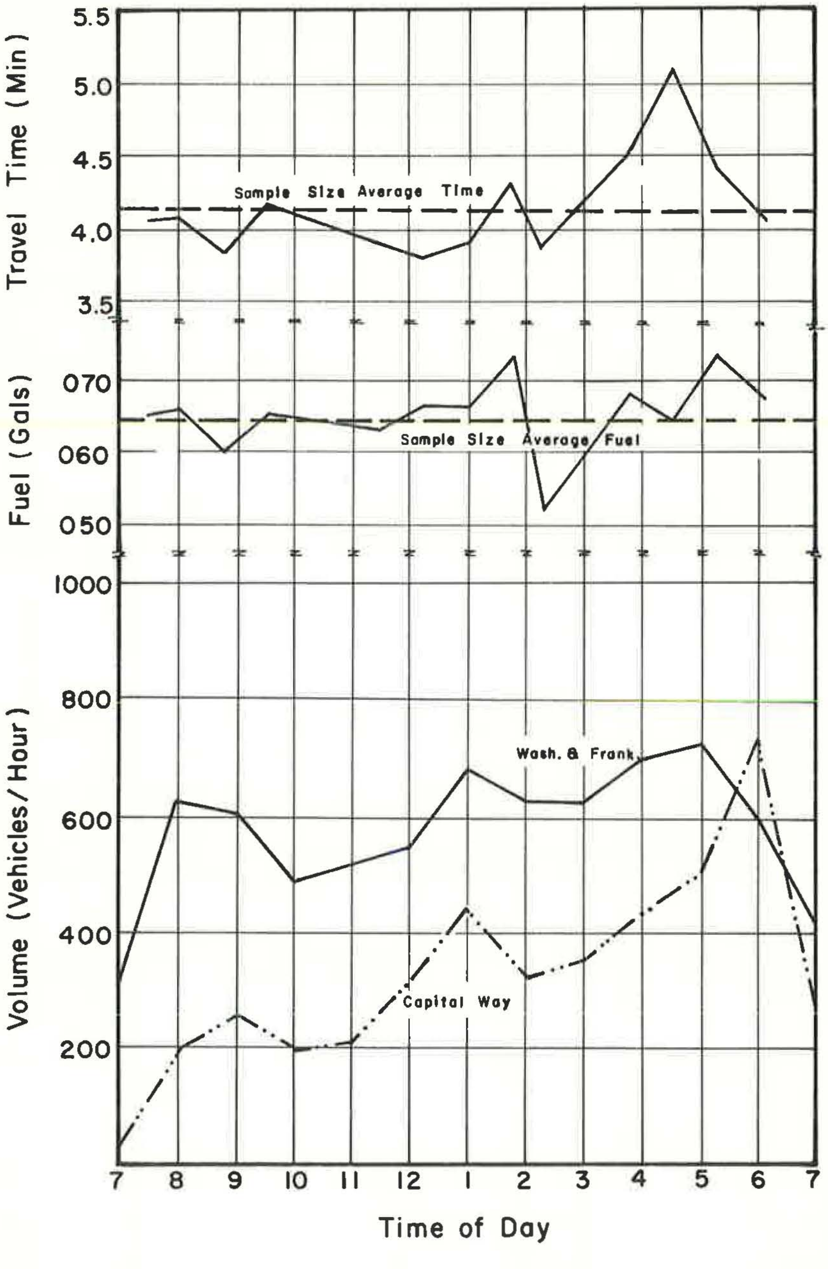


Figure 11. Route fuel consumption and traffic volume by time of day compared to daily average for US 99 business route, Olympia (E-S).

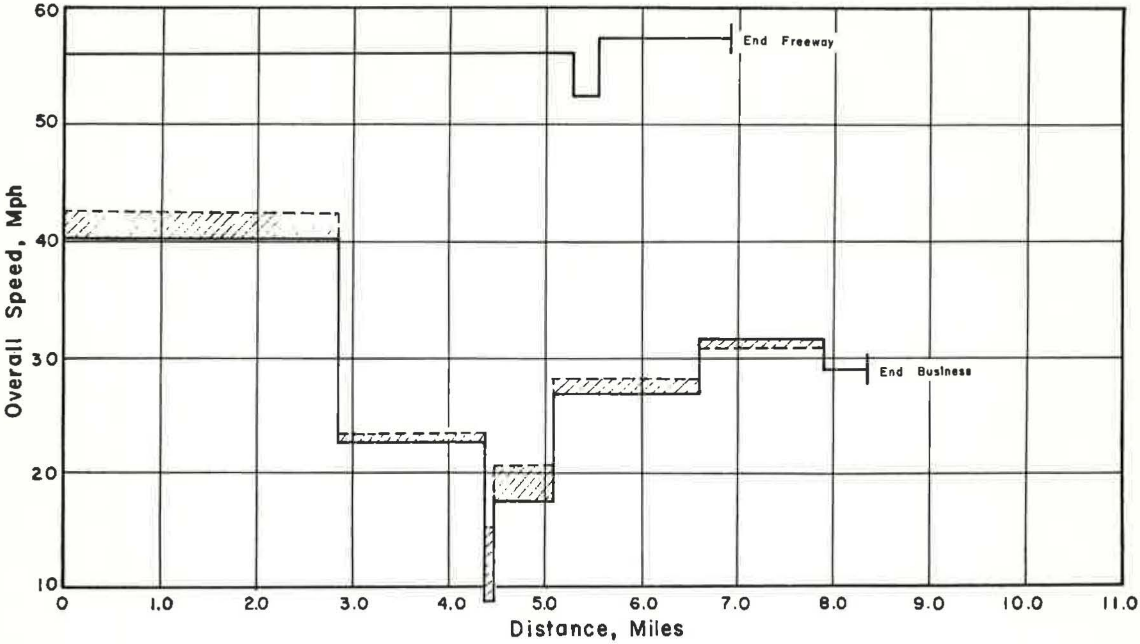


Figure 12. Overall speed and speed differential as level of service in 1963 by business and freeway routes for US 99, Olympia (E-S).

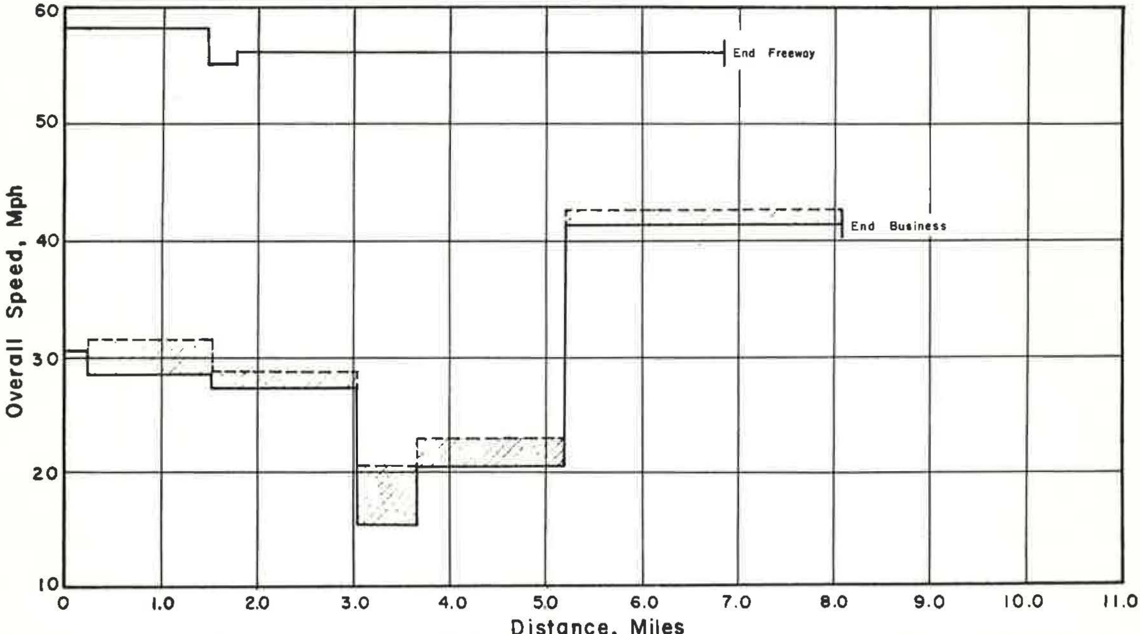


Figure 13. Overall speed and speed differential as level of service in 1963 by business and freeway routes for US 99, Olympia (S-E).

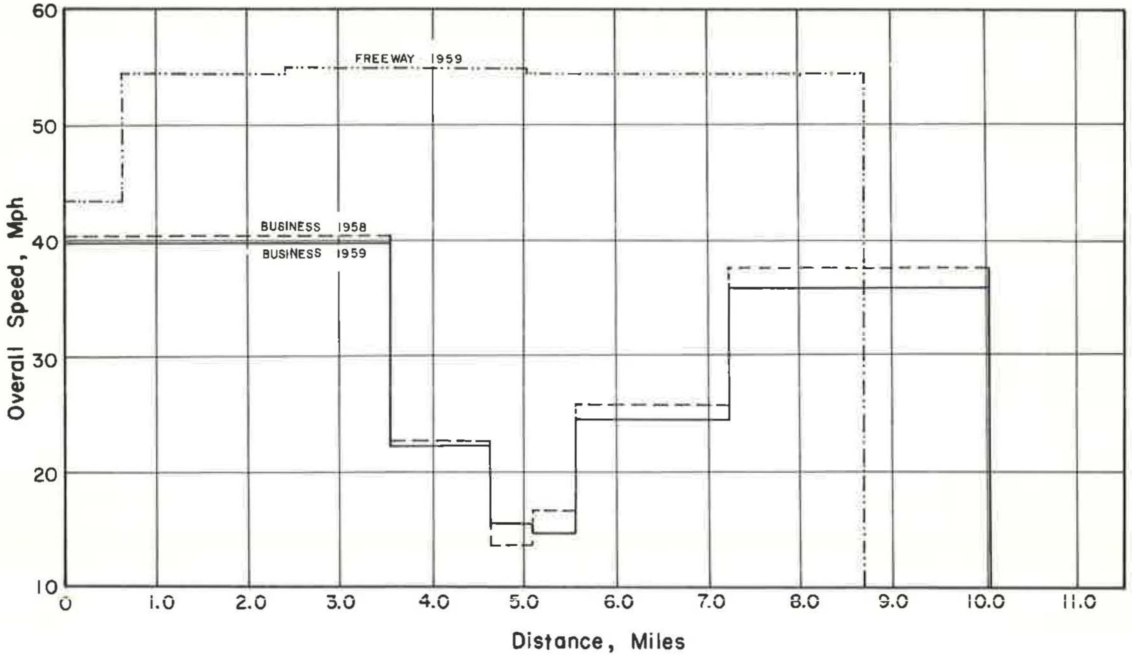


Figure 14. Overall speed as a level of service in 1958 (before) and 1959 (after) on business and freeway routes for US 99, Olympia (E-S).

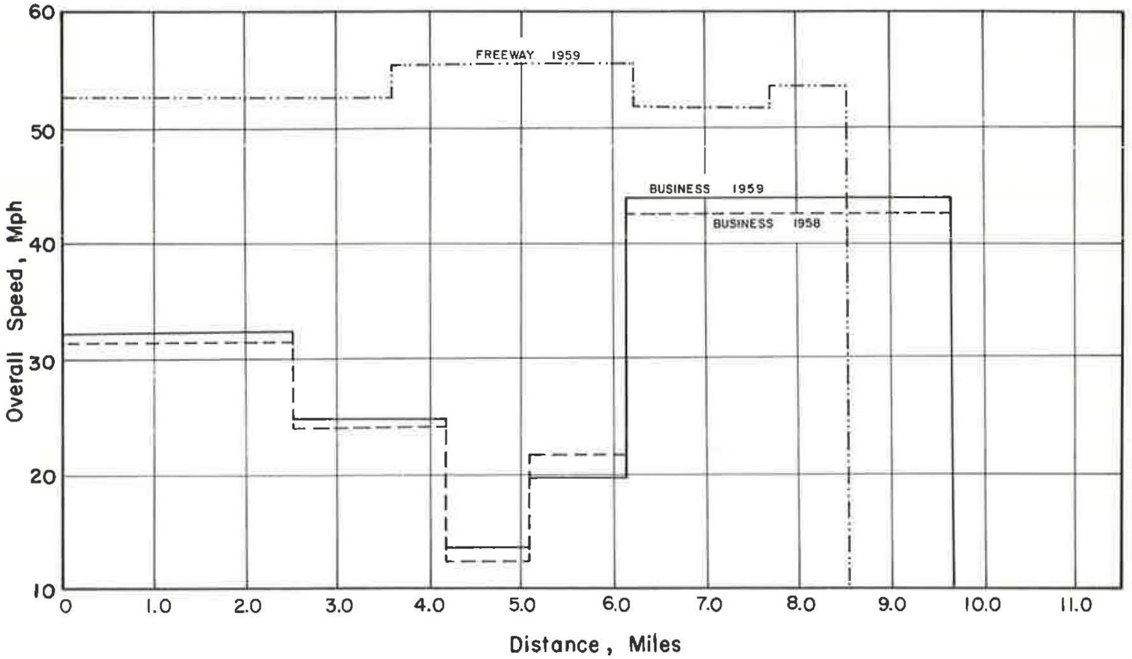


Figure 15. Overall speed as a level of service in 1958 (before) and 1959 (after) on business and freeway routes for US 99, Olympia (S-E).

vice. In some instances the reduction in the overall speed is still an acceptable level of service, particularly when traversing from a suburban area to a downtown area. Of more significance in the downtown area is the amount of delay or the difference between the overall and the running speeds.

The magnitude of the spread between the overall and the running speeds indicates to some individuals the potential of a deficiency in level of service. However, to others it is more desirable to indicate the location of delay, the number of delays and the length of time of each. Figures 12 and 13 show a difference between operating and running speeds which could be the result of one long delay or numerous short delays. Both are a source of irritation to the driving public; however, the number of stops causes more reaction from the driver and at the same time creates additional wear on the vehicle which is not immediately apparent to the driver. Figure 16 shows the number of delays, total delay and average delay for a typical test run on the Olympia US 99 business route in 1963.

Traffic Volume Relief

Many studies have utilized traffic volume counts for an evaluation of one route vs another or for before and after studies. It is logical to assume that the level of service could be raised if traffic volume is decreased. Until such time as a definite relationship can be established between traffic volume and road user costs, traffic volume should only be considered as an indicator of relief. For the Olympia bypass study, directional daily volume variations are indicated for 1958, 1959 and 1963 at comparable locations (Figs. 17 through 20). The hourly volume variation for these same years on the business route is shown in Figures 21 through 24 and the daily volume relief along the US 99 business route is indicated in Figures 25 and 26. These figures show that there has been a definite reduction in the level of traffic volume on the Olympia US 99 business route; this can be attributed to the opening of the freeway bypass. It can also be seen that during the peak hour in 1958 the level of traffic volume was considerably greater than that observed in 1963.

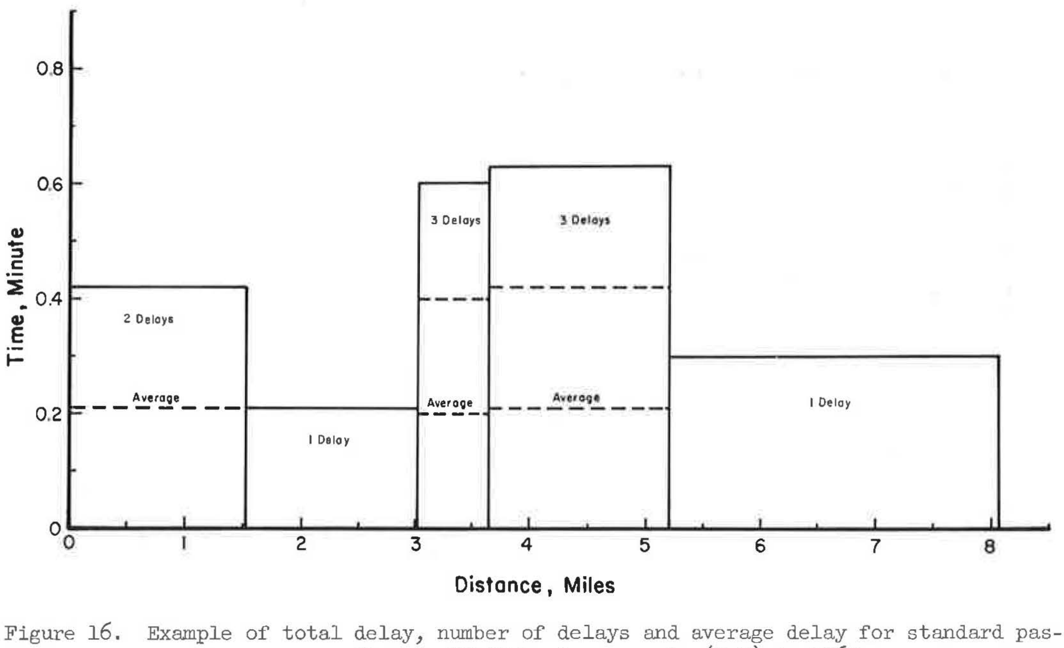


Figure 16. Example of total delay, number of delays and average delay for standard passenger car on Olympia US 99 business route (S-E) in 1963.

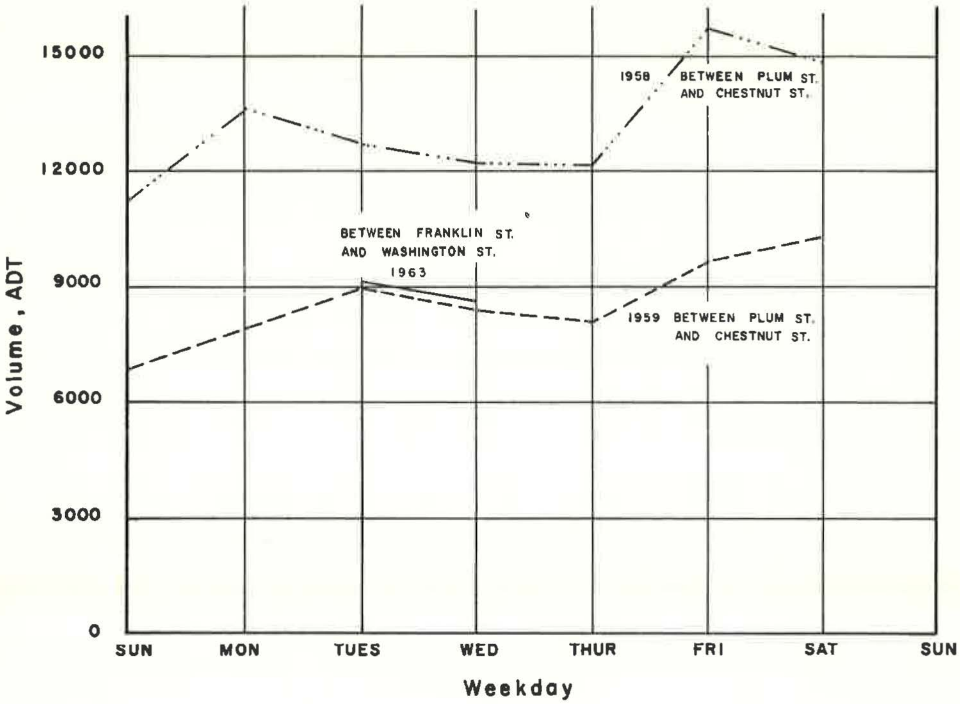


Figure 17. Daily volume variation on US 99 business (E-S) and US 410 business (E-W) for 1958 (before), 1959 and 1963 (after) on State Ave. E. in Olympia.

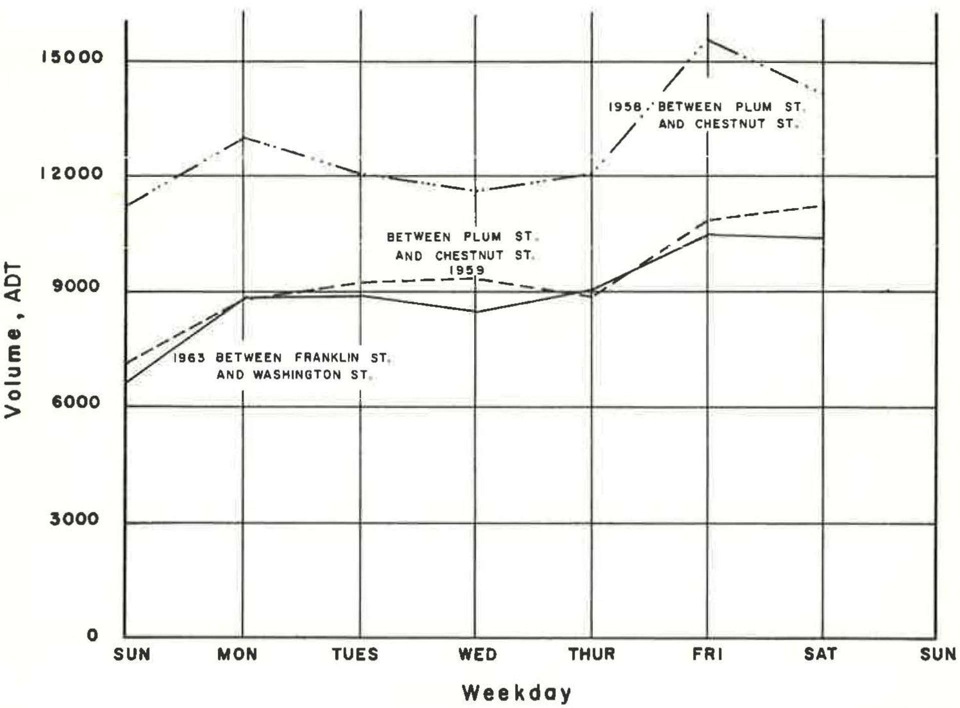


Figure 18. Daily volume variation on US 99 business (S-E) and US 410 (W-E) for 1958 (before), 1959 and 1963 (after) on the 4th Ave. E. in Olympia.

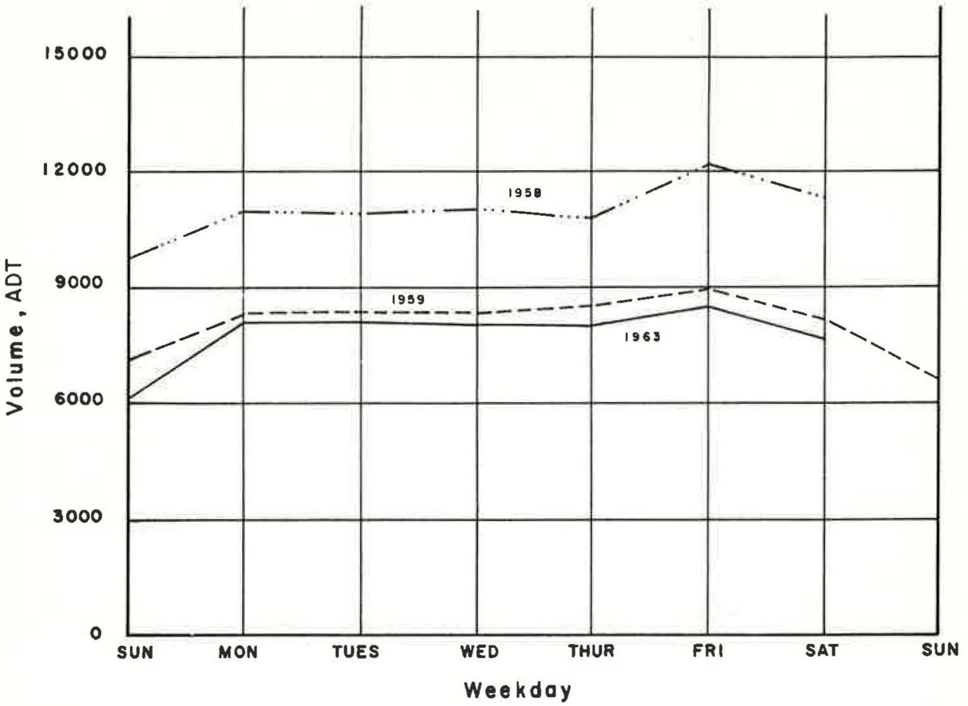


Figure 19. Daily volume variation on US 99 business (E-S) and US 101 business (W-S) for 1958 (before), 1959 and 1963 (after) on Capital Way at freeway overpass in Olympia.

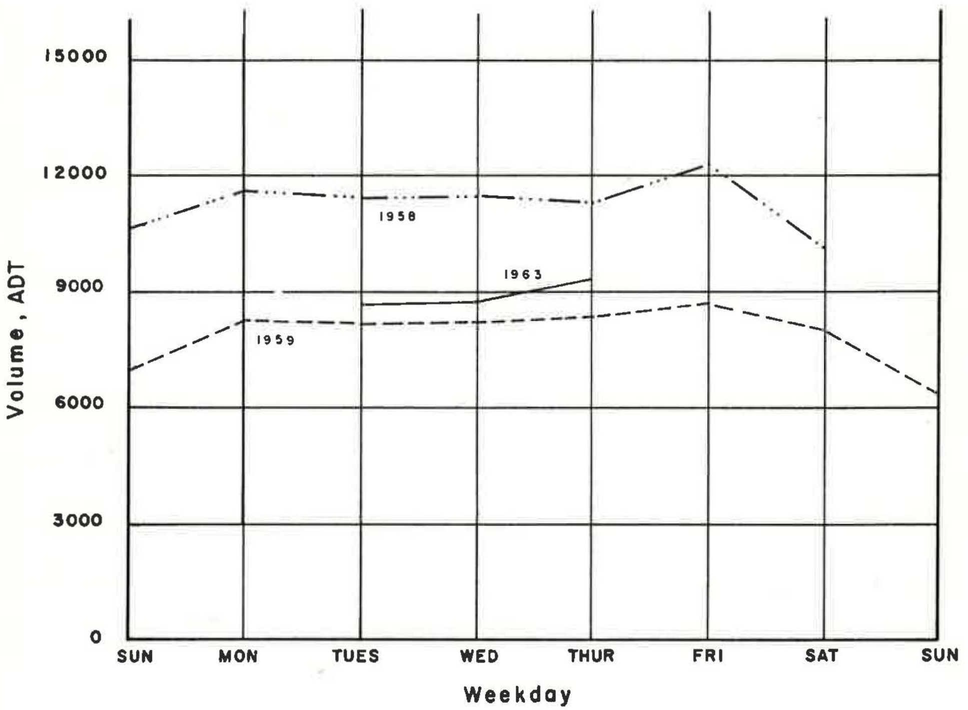


Figure 20. Daily volume variation on US 99 business (S-E) and US 101 business (S-W) for 1958 (before), 1959 and 1963 (after) on Capital Way at freeway overpass in Olympia.

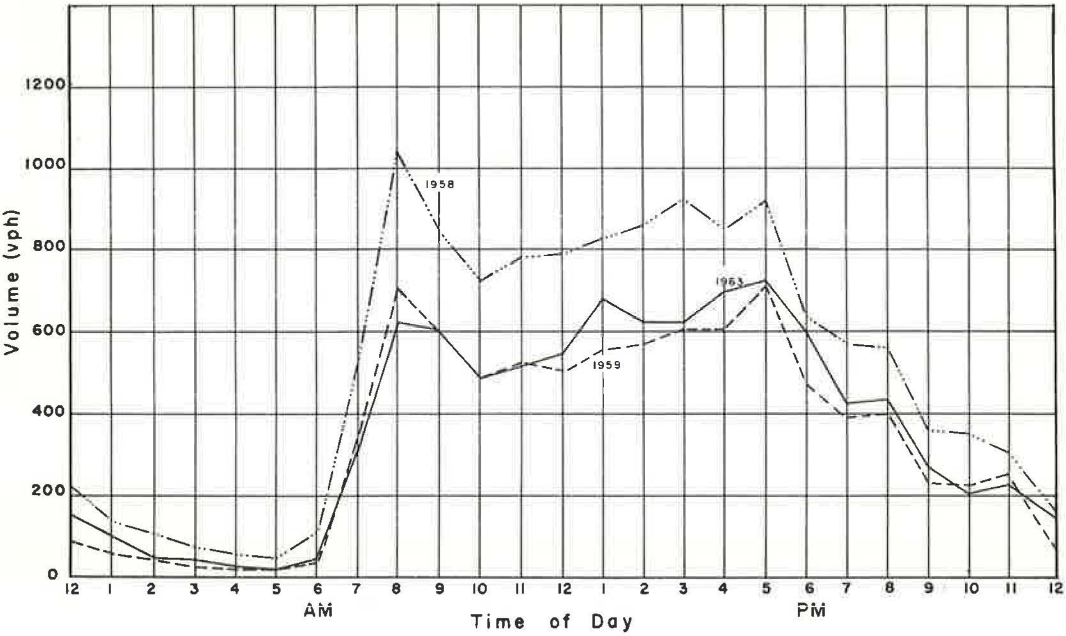


Figure 21. Hourly volume variation on US 99 business for 1958 (before), 1959 (after) on State Ave. between Plum and Chestnut Sts. and for 1963 (after) on State Ave. between Washington and Franklin Sts. in Olympia.

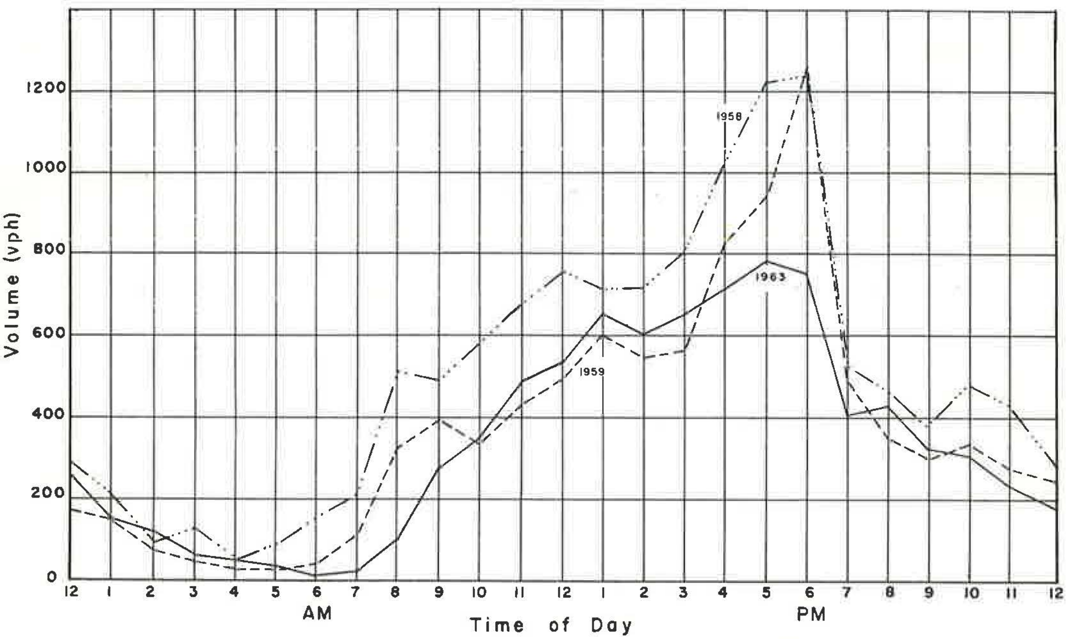


Figure 22. Hourly volume variation on US 99 business (S-E) for 1958 (before), 1959 and 1963 (after) on 4th Ave. between Washington and Franklin Sts. in Olympia.

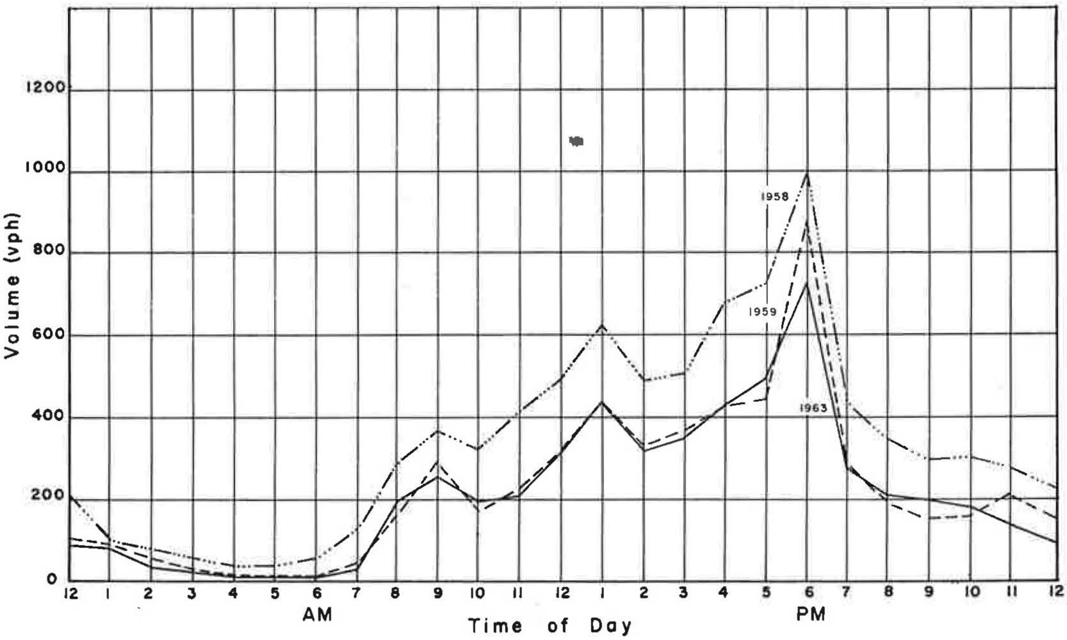


Figure 23. Hourly volume variation on US 99 business (E-S) and US 101 business (W-S) for 1958 (before), 1959 and 1963 (after) on Capital Way in Olympia.

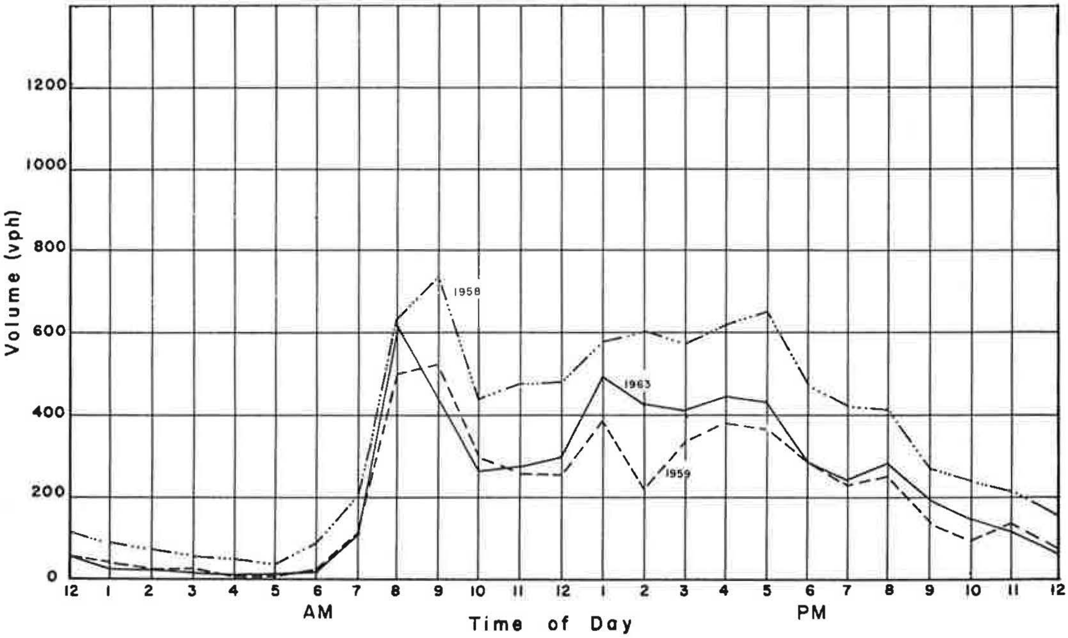


Figure 24. Hourly volume variation on US 99 business (S-E) and US 101 (S-W) for 1958 (before), 1959 and 1963 (after) on Capital Way in Olympia.

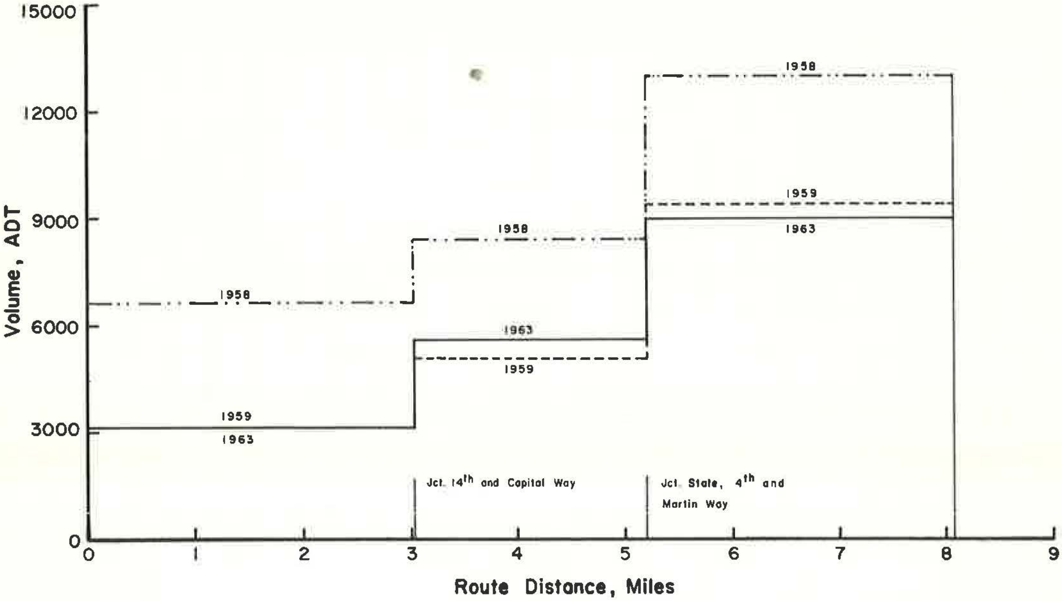


Figure 25. Relief in traffic volume along US 99 business route (S-E) in Olympia.

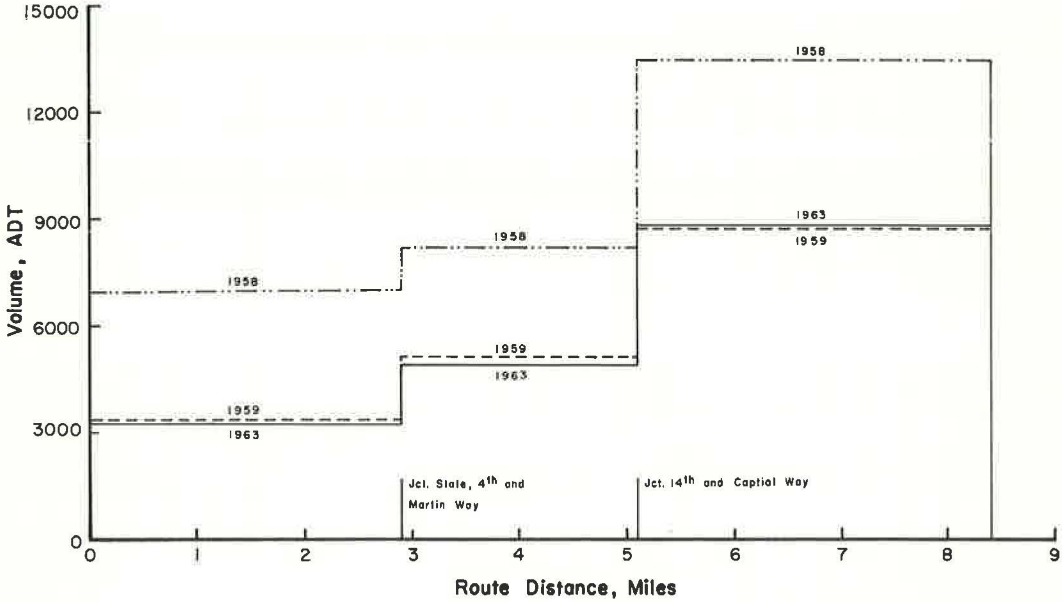


Figure 26. Relief in traffic volume along US 99 business route (E-S) in Olympia.

Appendix B

OVERALL SPEED SUMMARY BY VEHICLE TYPE ON THE SEATTLE-TACOMA FREEWAY ROUTE[a]

Vehicle Type	Travel Time[b]				Spot Speed[c]			
	No. Veh		Speed (mph)		No. Veh		Speed (mph)	
	S. B.	N. B.	S. B.	N. B.	S. B.	N. B.	S. B.	N. B.
Compacts	31	23	57.805	60.499	37	-	54.892	-
Std. pass. car	102	83	59.654	60.122	174	200	56.425	55.460
Pickups and panels	17	20	56.733	55.056	8	25	56.750	56.240
SU	4	19	53.071	51.868	14	14	52.286	45.256
Truck and trailer	-	-	-	-	21	15	48.381	46.267
Diesel	16	9	47.544	46.209	-	-	-	-
Gas	4	14	48.100	47.607	-	-	-	-

[a]Weather conditions on Jan. 16, 1963, PM, overcast; May 14, 1963, AM, clear; and June 12, 1963, AM, overcast and PM, broken clouds.

[b]Travel time observations were made on June 12, 1963: S.B. observations between 10:30 AM and 12:00 noon, and N.B. observations between 12:45 and 2:15 PM by the University of Washington using the license plate method.

[c]Spot speed observations were made by the State District Traffic Engineer; S.B. observations on May 14, 1963 between 10:10 and 11:10 AM, and N.B. observations on Jan. 16, 1963 between 1:15 and 2:10 PM. A radar speed meter was utilized to obtain the data.

Appendix A

TEST VEHICLE DESCRIPTIVE DATA

Test Unit No.	Axle Classif.	Year of Manuf.	Body Type	Wheel Base (in.)	Overall Length (in.)	Fuel Type	Cylinders: No.	Cylinders: Displacement (cu in.)	Mfrs. Net Hp	Rpm	Rear Axle Gear Ratio	Transmission: Type	Transmission: Ratio 1st	Ratio 2nd	Ratio 3rd	Ratio 4th	Transmission: Range Low	Range Hi	Range Reverse	Tire Size	Gross Veh. Wt.[a] (lb)
1	2	1962	4-door	109.5	181.1	gasoline	6	170	101	4,400	3.50:1	Auto	-	-	-	-	1.75:1	1:1	1.5:1	6.00 × 13	3,100
2	2	1962	4-door	119	209.6	gasoline	V-8	283	170	4,200	3.36:1	Auto	-	-	-	-	4.55:1-1.32:1	4.55:1-1:1	4.55:1-1.32:1	7.50 × 14	4,180
3	2	1962	pickup	127	206	gasoline	6	235	110	3,600	3.90:1	Std	2.94	1.68	1.00	-	-	-	-	6.70 × 15	4,500
4	3-S2	1955	tractor and flatbed	514	544	diesel	6	743	275	2,100	-[b]	Std	-[b]	-[b]	-[b]	-[b]	-	-	-	10.0 × 20	48,175
5	SU2D	1962	cab over 18-ft-van	153	24.75	gasoline	V-8	327	160	4,000	-[b]	Std	7.06	3.58	1.71	1.00	-	-	-	10.0 × 22	13,000 part 25,360 full
6[b]	2	1963	4-door hard top	119	210.4	gasoline	V-8	283	195	4,800	3.36:1	Auto	-	-	-	-	3.82:1-1.82:1	3.82:1-1:1	3.82:1-1.82:1	7.50 × 14	3,740

[a]Includes wt. of driver, observer and test equipment with units 3, 4 and 5 loaded with additional wt. to obtain avg. gross veh. wt. recorded by Highway Planning Division in Seattle-Tacoma test site.
[b]Not available.

Figure 27 illustrates preliminary results of fuel consumption in gallons per mile with corresponding overall speed as observed on the old route of US 99 between Seattle and Tacoma. Both before and after fuel rates are shown, as well as the rate at constant speed on the freeway section, for a standard passenger car. A wider variation may be expected in the fuel rates for the old section with traffic volume and signals interfering with the traffic flow along the route. A manual fit of curves to the data shows curves on the old section similar to the freeway data at constant speed. This figure also shows the range of speed observed with the after values within a narrower speed range.

Traffic Volume vs Fuel and Overall Speed

Ideally the economic variables of fuel and travel time (overall speed) should be related to traffic volume. A more comprehensive analysis might develop a family of curves for highway types. A sample of this relationship for a standard V8 passenger car operating on the old US 99 route between Tacoma and Midway, a 4-lane undivided suburban major arterial, is represented in Figure 28. From such a relationship it would be relatively simple to calculate the total fuel and travel time on an existing facility if the traffic volume is known. Additional research is necessary to determine to what degree traffic volume data is required on existing facilities and also planned facilities. If 15-min or hourly volumes are necessary, the problem of predicting fuel and travel time on planned facilities is more complex. The data presented in Figure 28 are actually the best data collected in this study. Greater control of the accuracy of volume counting is considered necessary to develop more reliable curve data.

Cost of Operation at Various Speeds

Accident costs are a major portion of the total cost of operation; however, it was not within the scope of this research to collect and analyze such data. Only total time and fuel costs (1) are presented in this report. The US 99 freeway between Tacoma and Midway is utilized in this example for test vehicles ranging from a standard passenger car to a tractor and trailer unit. Time cost is an asymptotic function of speed and fuel costs are obtained from Figure 9. The total cost curve is the addition of the fuel and time curves. Figure 29 shows an optimum speed (maximum benefit) of 70 mph for the standard passenger car and 55 mph for the tractor and trailer, but with a much narrower range of operation.

Additional research on other types of facilities may provide a realistic means of evaluating the proper speed level.

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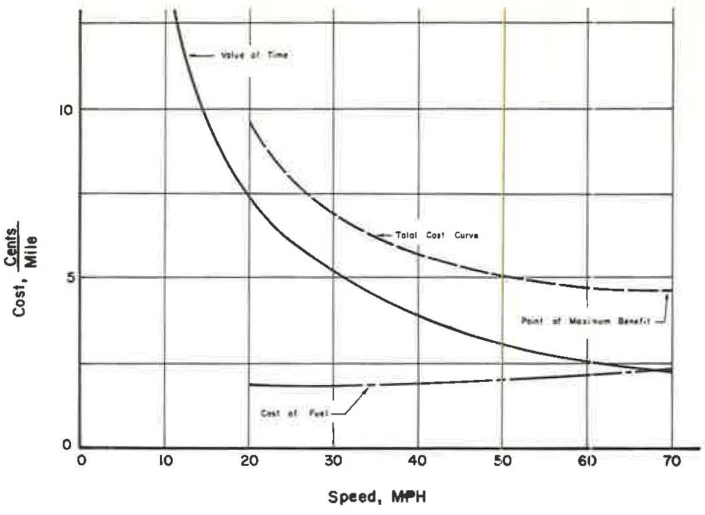
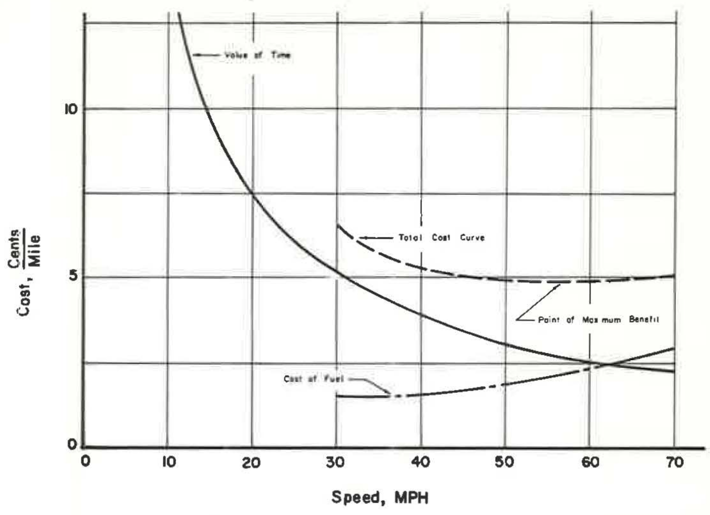
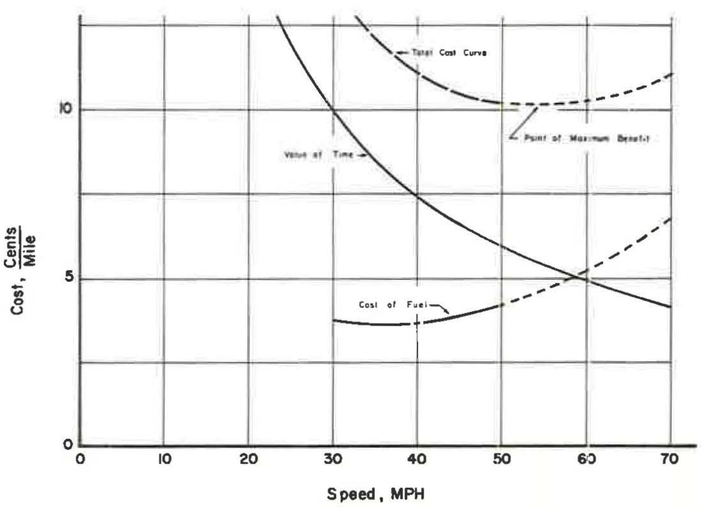
1. "Road User Benefit Analysis for Highway Improvements." Amer. Assoc. of State Highway Officials, 152 pp. rev. (1960).
2. Kieling, W. C., "Fuel Meter Model FM 200." HRB Bull. 334, pp. 47-53 (1962).
3. Sawhill, R. B., and Firey, J. C., "Motor Transport Fuel Consumption Rates and Travel Time." HRB Bull. 276, pp. 35-91 (1960).



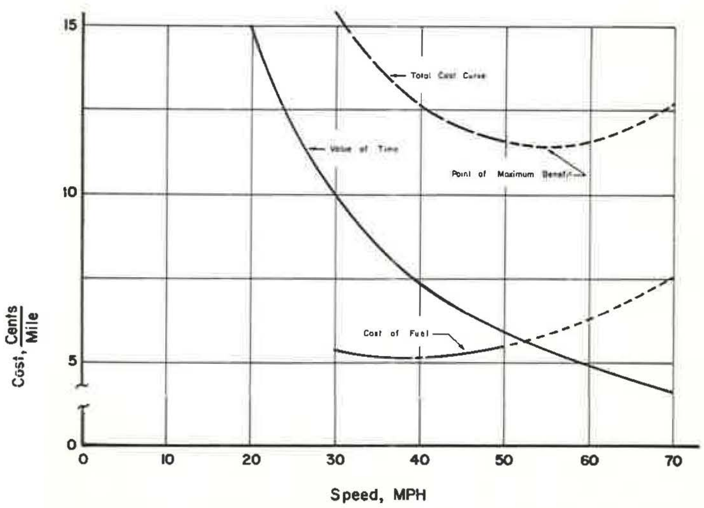
Relationship of Value of Time to Cost of Fuel, for a standard 4-door V-8 sedan.



Relationship of Value of Time to Cost of Fuel, for a half ton pick-up.



Relationship of Value of Time to Cost of Fuel, for a single unit truck.



Relationship of Value of Time to Cost of Fuel, for a diesel tractor and trailer.

Figure 29. Example of optimum speed for various types of vehicles on typical freeway.

ANALYSIS OF SPEED, FUEL, TRAVEL TIME, VOLUME RELATIONSHIPS AND COSTS

This research study has substantiated previous results and has presented new relationships as outlined in the following:

Fuel in Gallons per Mile vs Speed

From previous studies by the research group it has been definitely determined that there can be consistent relationships developed between fuel consumption and constant speed of operation. For the Seattle-Tacoma freeway study, the new section was utilized for running constant speeds and observing the corresponding fuel consumption (Figs. 8, 9). The section was basically an uphill route in a northbound direction and downhill in the southbound direction. The total amount of rise is 606.84 ft northbound and 318.68 ft southbound. It should be kept in mind that this overall speed is constant and the vehicles are operated on an open section of freeway where traffic volume and control devices are not a factor. The general shape of these curves indicates that as the vehicle size increases, the curve becomes more U-shaped, with the optimum fuel consumption at a speed of about 40 mph for the larger truck. However, the passenger cars operate most efficiently at low speeds. These characteristics should be recognized in evaluating the difference in fuel consumption on a freeway at speeds of 60 to 70 mph vs speeds of 20 to 25 mph on a business route. In such cases the savings in time may be considerable, whereas the savings in fuel would be a negative quantity, as previously illustrated for the Seattle-Tacoma study.

Fuel in Gallons per Mile vs Observed Overall Speed

Vehicles on highway facilities, except freeways or highways without impeding traffic control devices and with low traffic volume do not all travel at uniform rates of speed.

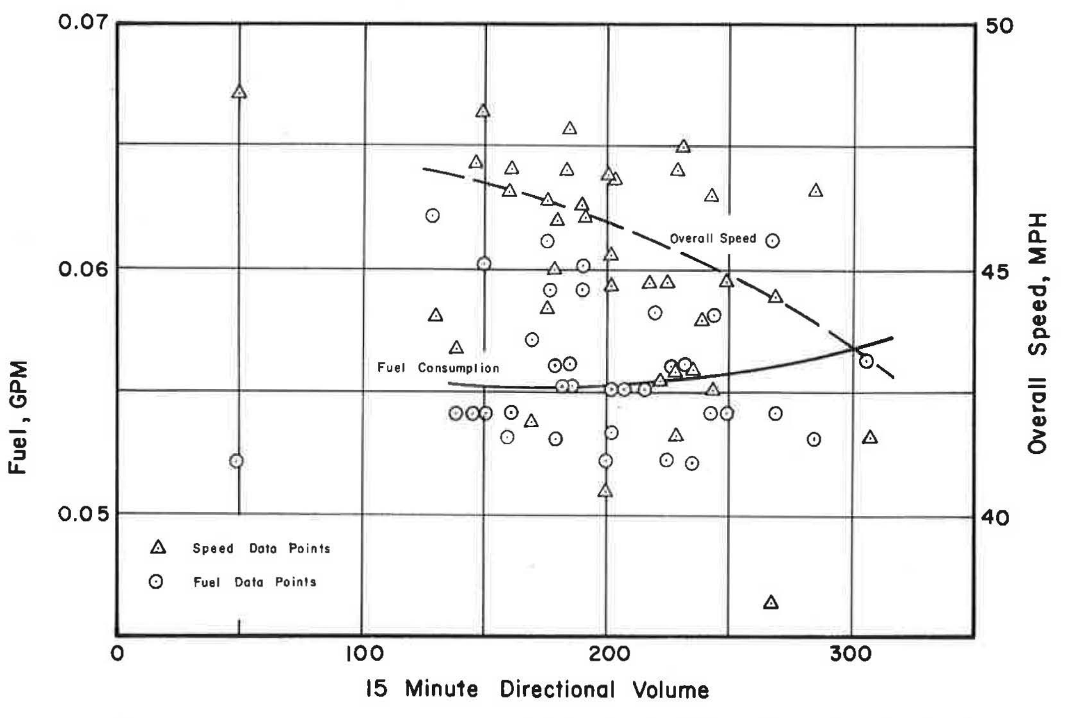


Figure 28. Relationship of fuel and travel time to traffic volume for standard passenger car on 4-lane suburban major arterial, US 99 old route (S-N).

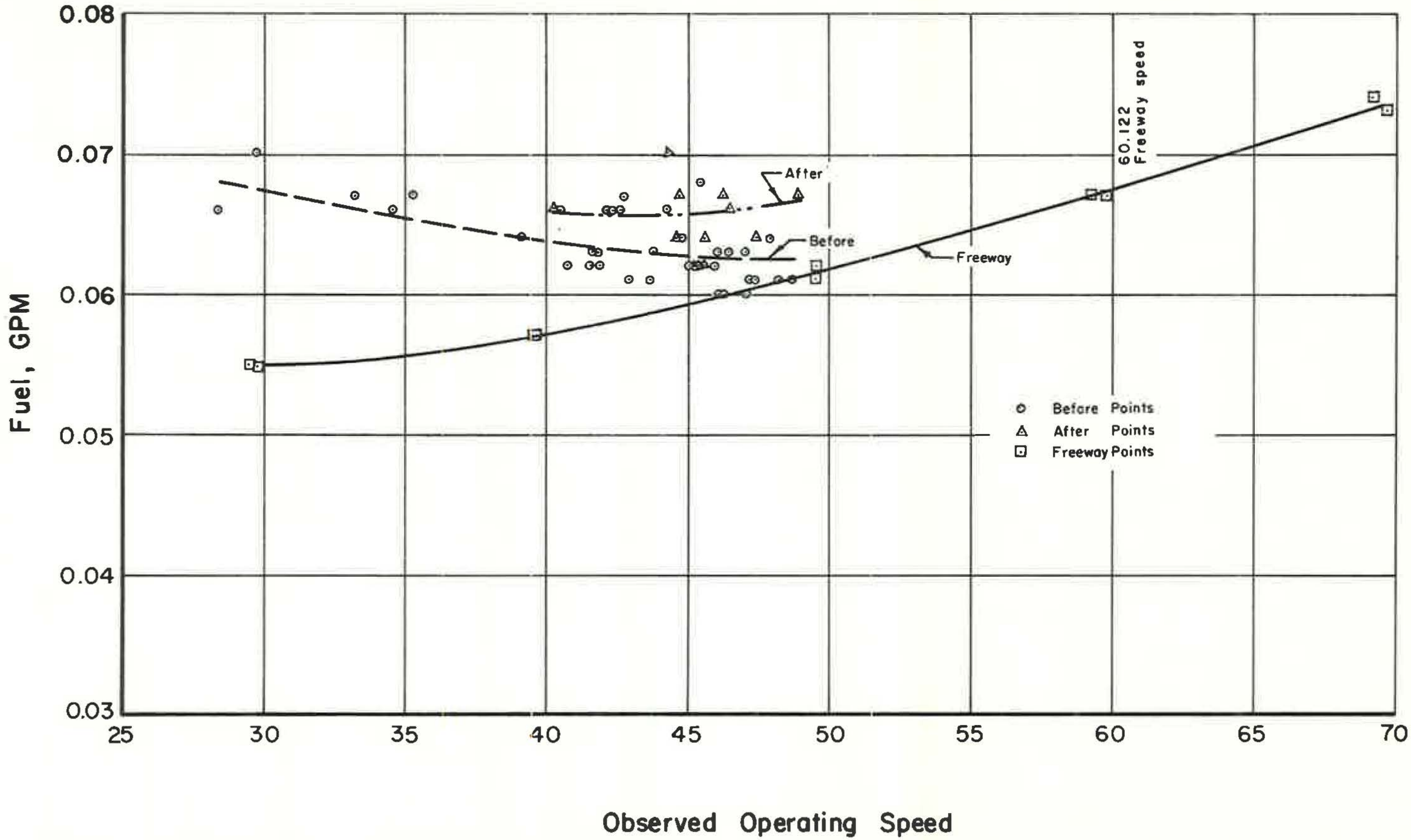


Figure 27. Relationship of fuel to overall speed for a standard passenger car on US 99 Seattle-Tacoma routes (S-N).

Appendix C

FUEL METERING DEVICES

The FM 200 (2) is a volumetric measuring device that separates out vapor so that only liquid is measured. During calibration at 71 F and measuring a quantity of 500 ml, the meter maintained a constant number of counts over a very large fuel flow range. The calibration was performed in a fuel lab using a 500 ml burette to obtain the calibration constant. The flow rate was controlled by a valve and fuel pressure was provided by an electric fuel pump. By means of the calibration constant counts could be converted to gallons by the following equations:

$$F_c = F_o - (68 - T_o)(C_e)(F_o) \tag{1}$$

$$C_c = \frac{N_o}{F_c} \times 3785.4 \tag{2}$$

in which

F_c = corrected fuel, ml;

F_o = observed fuel, ml;

T_o = observed fuel temperature, F;

C_e = fuel expansion coefficient at 1 F;

C_c = calibration constant, counts/gal; and

N_o = number of counts observed.

Eq. 1 is used to correct the fuel volume measured to a standard temperature of 68 F; using this corrected volume, Eq. 2 converts counts per milliliters to counts per gallon. A component part of the FM 200 is a digital counter operating from the vehicle electrical power supply. The counter can be brought to zero or turned on and off at will. For electrical continuity the FM 200 meter and the counter must be connected as they are wired in series. This is essential because the FM 200 requires electrical power to operate solenoids which position the metering valve.

The burette board (3) is a volumetric measuring device that reads directly in milliliters. This device requires no calibration but presents a problem of accurate readings while the vehicle is accelerating because the level of the liquid surface in the burette and its corresponding reading in the calibrated tubes (Fig. 4) vary. To obtain accurate readings the drivers must avoid accelerations and decelerations while passing fuel recording points. Although this was a restriction to the drivers' normal habits the distances concerned were insignificant in comparison to the route distances. Because vapor is vented to the atmosphere, only liquid is measured. The conversion constant of 3785.4 ml per gal was used to convert the fuel consumed after it had been adjusted for temperature.

Operation of the burette board requires the use of both hands because two valves are operated in rapid succession. First the burette that is being drawn from is turned off, then the next burette is turned on. The operation of the burette board type of meter requires very close attention, because it is possible to obtain false readings if the valves are not manipulated correctly.

The temperature gage used with the meters was a dial reading immersion type that read in degrees F. Temperature was recorded at the outlet on the engine side of the meters. Care was used to mount the temperature gage clear of the engine radiator when using the FM 200 to avoid errors caused by the heated air flow from the radiator. With the FM 200, the fuel temperature was recorded only at the beginning and end of the test runs. The installation with the burette board was the same as shown in Figure 4 and allowed fuel readings throughout the entire run.

Appendix D

TRAVEL TIME COLLECTION

The stopwatches as used with the FM 200 (Fig. 5) were mounted on the data recording board with the section time watches side by side so that they could be started and stopped simultaneously. The delay watch was mounted on the opposite side of the board to decrease the chance of observer error during recording. The driver's watch was mounted in the center of the steering wheel with the start button up for ease of operation.

When using the burette meters the driver's watch was mounted as with the FM 200, whereas the observer had only the delay watch mounted on the data recording board. The accumulative time watch was mounted on the burette board in a position for easy observation while operating the burette valves. At the beginning of the run the valve to the engine was closed at the same instant that the watch was started; then the valve to the first burette was opened. The slight delay in opening the burette valve made no difference in the fuel used during the first section. The time was then allowed to accumulate as the valves were operated at each additional checkpoint.

Appendix E

VOLUME WEIGHTING PROCEDURES

The following tables based on the 1963 study of US 99 business route (E-S) in Olympia, show the procedure used to adjust the sample size weighted peak averages, using the actual percent volume to obtain the volume weighted average.

Count Location[a]	Section Affected
No. 27	1 to 2
State St. between Washington and	2 to 3
Franklin	3 to 4
No. 7	4 to 5
	5 to 6
	6 to 7

[a]See Figure 1.

PERCENTAGE OF ADT AT VARIOUS COUNT LOCATIONS

Location	AM Peak	PM Peak	Off-Peak
No. 27	6.97	9.34	83.69
State	8.33	7.44	84.23
No. 7	7.50	15.23	77.27

FUEL WEIGHTING

Sect.	AM Peak			PM Peak			Off-Peak		
	Avg. Fuel	Vol. Factor	Product	Avg. Fuel	Vol. Factor	Product	Avg. Fuel	Vol. Factor	Product
1-2	0.1802	0.0697	0.0126	0.1752	0.0934	0.0164	0.1714	0.8369	0.1434
2-3	0.0666	0.0833	0.0055	0.0644	0.0744	0.0048	0.0633	0.8423	0.0533
3-4	0.0048	0.0833	0.0004	0.0100	0.0744	0.0007	0.0077	0.8423	0.0065
4-5	0.0614	0.0750	0.0046	0.0706	0.1523	0.0108	0.0634	0.7727	0.0490
5-6	0.1026	0.0750	0.0077	0.1004	0.1523	0.0153	0.0926	0.7727	0.0716
6-7	0.1208	0.0750	0.0091	0.1128	0.1523	0.0172	0.1143	0.7727	0.0883

SUMMATION OF WEIGHTED VALUES

Section	AM Peak	PM Peak	Off-Peak	Total
1-2	0.0126	0.0164	0.1434	0.1724
2-3	0.0055	0.0048	0.0533	0.0636
3-4	0.0004	0.007	0.0065	0.0076
4-5	0.0046	0.0108	0.0490	0.0644
5-6	0.0077	0.0153	0.0716	0.946
6-7	0.0091	0.0172	0.0883	0.1146
Total				0.5172