Vehicle Characteristics of Fuel and Travel Time on Urban Arterials and Freeways

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This report evaluates the impact that urban freeways have on vehicle operating characteristics of travel time and fuel consumption. The study is unique in that seldom has a before-and-after study been conducted as comprehensively or over as long a period as this project. The "before" portion was conducted in 1962 before any freeways were open to traffic in the Seattle area. The "after" portion was conducted in the summer of 1968, approximately 6 months after the Seattle Freeway was completely open to traffic. Travel time and fuel consumption data were collected for five classifications of vehicles operating over four parallel arterial routes as well as on the freeway. On only two of the parallel routes was there a statistically significant reduction in traffic volume with a corresponding savings in travel time. The total time savings benefit for 1968 as a result of the freeway construction was $30,737,000, or about 12 percent of the construction costs. The evaluation of the fuel consumption benefit presented some difficulty. The vehicles used in the after portion were calibrated with their counterparts in the before study. Constant speed calibration does not appear to adequately represent a vehicle adjustment factor when applied on routes with variable operating speeds. Stratification of traffic volume into peak and off-peak periods was also required. In general, statistically significant savings were observed for the passenger car on two of the secondary routes but not on the major parallel route, even though a time savings was experienced. The major fuel benefits accrued to passenger cars directed from the old arterial route to the freeway. At all time periods the diesel truck experienced fuel savings on the freeway compared to its operation on the old major arterial route. Despite a small negative fuel benefit for vehicles continuing to operate on the arterial routes, the total system fuel savings is $366,000 for 1968. Approximately 25 percent of this benefit is attributable to diesel-powered vehicles.

• THE MEASUREMENT of vehicle operating characteristics of travel time and fuel consumption is certainly not a new technique to the engineering profession. However, the application of the most practical methods and equipment to network or corridor travel to evaluate the impact before and after freeways are constructed in an area is not generally researched. In 1962 the University of Washington entered into a research contract with the Washington Department of Highways and the U. S. Bureau of Public Roads to perform the "before" portion of such a study in the Seattle area. At that time, sections of the Seattle Freeway were under construction but were not open to traffic. The "after" portion of the study was conducted in the summer of 1968 when the Seattle

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Freeway was open to traffic through and beyond the city limits of Seattle. The impact evaluation considered travel time, fuel consumption, and accidents on four parallel arterial routes in the north-south corridor.

TEST ROUTES

The routes, shown in Figure 1, were subdivided into sections for comparison of travel time and fuel consumption over shorter distances. Travel time sections average about ¾ mile in length, whereas fuel sections, which require a sufficient distance to

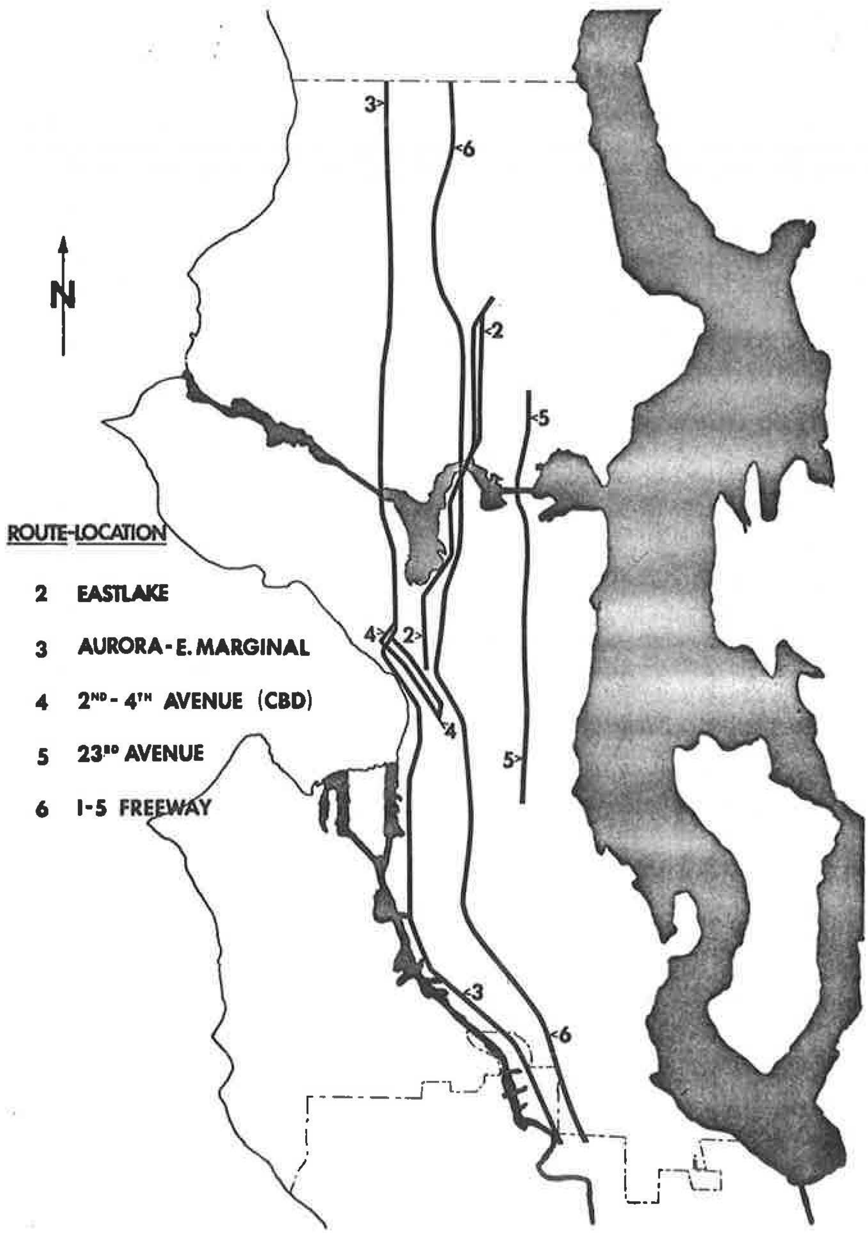

Figure 1. Seattle area test routes.

provide an adequate quantity of fuel for reliable fuel consumption measurements, are about 2 miles in length.

One additional test section, used for vehicle-calibration purposes, was located approximately 11 miles south of Seattle on Interstate 5. This route was used to measure fuel consumption at several constant speeds for each of the five test vehicles. A summary description is given in the following.

Route 2

Test Route 2, a Seattle arterial that closely parallels the route of the freeway, is a section of State Route 522. The route begins at Fairview Ave. and Denny Way, crosses under the freeway just south of the Lake Washington Ship Canal, and extends northward to the terminal point at 15th Ave. N.E. and Lake City Way (formerly Bothell Way). The portion of the route north of the canal is a one-way couplet with 11th and 12th Avenues N.E. northbound and Roosevelt Way N.E. southbound.

Route 3

Old US-99, formerly the major north-south route through Seattle, is designated as Route 3. The route begins at the Duwamish junction and extends northward on E. Marginal Way, the Alaskan Way viaduct, the Battery St. tunnel, and Aurora Ave. to the north city limits of Seattle at N. 145th St. The route is approximately 17 miles in length, and is between 1 and 2 miles west of the Seattle Freeway. The traffic conditions near the south end, from the Duwamish junction to the Spokane St. overcrossing, are strongly influenced by traffic generated by the Boeing Company.

Route 4

Test Route 4 is the shortest of the routes. It includes a portion of the old US-99 business route, and consists of sections of 2nd Ave. and 4th Ave. forming a one-way couplet in the Seattle central business district. Although it was anticipated that the freeway would have an influence on the traffic operations on this route, it must be noted that many other variables can similarly affect travel in the CBD.

Route 5

Route 5 extends northerly from the intersection of 23rd Ave. and Rainier Ave. S. to the intersection of 25th Ave. N.E. at E. 55th St. Part of this route coincides with State Route 513. It was expected that the freeway would not significantly affect this route, but that it would be relieved by the construction of the proposed R. H. Thomson Expressway.

Route 6

The Seattle Freeway, Interstate 5, from E. Marginal Way to N. E. 145th St. was designated as Test Route 6. This facility has a minimum of six lanes, and the portion from Yesler St. to N. 110th St. has an additional reversible roadway. The first section of this route opened to the public was the Freeway Bridge over the Lake Washington Ship Canal (December 18, 1962). The main roadway was completed with the removal of the southbound detour between the Dearborn and Spokane St. interchanges (August 24, 1967).

Route 7

A 12.8-mile section of Interstate 5 between the Port of Tacoma Road (Pierce County) and S. 240th St. (King County) was used for vehicle calibration, and is referred to as Test Route 7. This route has not been redesigned or modified since the 1962 study.

TEST VEHICLES

A group of five test vehicles, chosen initially in 1962, was selected to be representative of the majority of vehicles in use on the highways. The test vehicles included a compact sedan, a standard 4-door sedan, a pickup truck, a single-unit truck with dual rear tires, and a diesel tractor-trailer unit (3S2). The details on vehicle specifications are given in Table 1. There are minor differences between the test vehicles used in the 1962 and the 1968 study. For the most part, these differences reflect an increase in horsepower (about 10 percent for the passenger vehicles, 30 percent for vehicle 50) resulting from improvements in engine design and components.

TEST EQUIPMENT

In a study and analysis of vehicle operating characteristics, it is necessary to gather accurate data on fuel consumption, travel time, distance, and traffic volumes. The basic test equipment used in this study is similar to that used in the before study.

Fuel Metering Devices

Two different devices are available for the accurate measurement of fuel consumption. A fuel meter, model FM 200, developed by the University of Washington was used on the passenger cars. This meter is designed to measure fuel over a broad fuel flow range, by counting the number of times that two small chambers within the meter have been filled with fuel and then emptied. The chamber volume is approximately 2.5 ml. A correction must be made for the volumetric change in fuel with a change in temperature. At each fuel checkpoint, the observer recorded the number of counts on the FM 201 counter assembly, which is located in the passenger compartment, and at the end of each test turn the fuel temperature registered on an immersion-type dial gage was recorded.

Because only one FM 200 was available for use in this study, and because concurrent operation of the cars and trucks was desired, it was necessary to use burette boards to measure truck fuel consumption. The burettes are read directly in milliliters of fuel used, although corrections must be made for fuel temperature. The fuel metering devices are discussed in detail in a previous report (1).

Time Measurement

Typical laboratory stopwatches, measuring time in increments of 1/100 minute, were used to measure travel and delay time. Standard accuracy tests were performed on the

TABLE 1

1968 TEST VEHICLE SPECIFICATIONS

Category	Vehicle Number				
	10	20	30	40	50
Axle class	2	2	2	3S2	SU2D
Year of manufacture	1961	1967	1965	1968	1968
Make	Falcon	Chevrolet	Chevrolet	White	Ford
Body type	2-door sedan	4-door sedan	Pickup	Tractor-trailer	Van truck
Wheelbase	110 in.	119 in.	127 in.	46 ft 0 in.	12 ft 9 in.
Overall length	181 in.	213 in.	206 in.	54 ft 0 in.	25 ft 0 in.
Fuel	Gasoline	Gasoline	Gasoline	Diesel	Gasoline
Cylinders	6	8	6	6	8
Displacement, cu. in.	170	283	250	743	361
Net horsepower at rpm	110/4400	195/4800	155/4200	220/2100	210/4000
Rear axles ratio: 1	3.50	3.08	4.11	4.88	7.20
Transmission type	Automatic	Automatic	Standard	Standard	Standard
Ratio: 1 (gear/ratio)	Low/1.75 High/1.00 Rev./1.50	Low/1.82 High/1.00 Rev./1.82	1st/N. A.[a] 2nd/N.A.[a] High/1.00	9th/1.35 10th/1.17 11th/1.00 12th/0.87 Rev./12.50	3rd/2.10 4th/1.17 5th/1.00 Rev./5.89
Tire size	6.50 × 13	8.25 × 14	7.75 × 15	10.00 × 22	9.00 × 20
Gross vehicle weight[b]	2,820	4,100	4,500	47,200	13,300

[a]N.A. = not applicable.
[b]Includes weight of driver, observer, and test equipment. Vehicles 30, 40, and 50 were loaded with additional weight to simulate typical driving conditions.

watches prior to the testing program. Side start watches were used to measure delay time for each section. Accumulated delay time and cause of delay were recorded by the observer. The driver measured total elapsed test route time with a stopwatch affixed to the center of the steering wheel.

Distance Measurements

Accurate distance measurements on all test sections were made using a calibrated survey odometer. The meter recorded to $^1/_{1000}$ mile. Route distances were measured three times, both northbound and southbound. Checkpoint locations were generally established at the centerlines of intersecting streets.

Traffic Volumes

An extensive traffic volume counting program was undertaken with the cooperation of the Washington Department of Highways and the Seattle Traffic Engineering Department. Counts were taken at one or more locations on each test route while the test vehicles were making runs. A catalog of all volume counts taken on these routes since 1965 was assembled. Records from several permanent count locations in the Seattle area were obtained for the purpose of establishing traffic volume variations.

ANALYSIS OF TRAVEL TIME SAVINGS

During the course of the after study, approximately 1,000 test runs were made. A similar number of runs were made during the before study, although in 1962 there was one less test route. Computer processing of the field data greatly facilitated the handling of these large amounts of information.

During the preliminary analysis of the 1968 data, test runs were separated according to test route, direction of travel, and type of vehicle. Unweighted averages were established for the categories of overall and running speeds, travel time and delay, and fuel consumption. Computer output from the 1962 study was in a similar format.

TRAVEL TIME DATA

One of the primary objectives of this study was to verify the effect of highway improvements in the Seattle area on vehicular travel time. It was felt that general trends in travel time changes might be noticed in an analysis of the original computer output. Several patterns were observed, but the variance of the results restricted any meaningful analysis of the data in this form.

The difficulty in establishing definite trends from the preliminary arrangement of data prompted a restructuring of the computer outputs to provide information on travel time as a function of time of day. Course time subgroupings were established as follows: morning peak hour—trips beginning between 7:15 and 8:14 a.m.; evening peak hour—trips beginning between 4:30 and 5:29 p.m.; and off-peak hour—trips beginning at all other times.

A review of the data separated according to test route, direction of travel, vehicle number, and time of day accentuated the trends of travel time reduction. Table 2 gives the results of a comparison of travel times for vehicles 2 and 20, which are similar to the majority of vehicles on

TABLE 2

TRAVEL TIME COMPARISONS STRATIFIED BY TIME OF DAY

Route	Time of Day	Travel Time in Minutes[a] Northbound 1962	Northbound 1968	Southbound 1962	Southbound 1968
2	Morning peak	15.46	12.12	19.66	14.11
	Evening peak	19.53	15.15	15.15	15.12
	Off-peak	14.41	12.75	13.62	13.59
3	Morning peak	33.36	31.19	40.51	30.75
	Evening peak	47.58	34.95	29.48	31.55
	Off-peak	30.65	29.58	31.31	29.27
4	Morning peak	6.82	7.40	5.94	6.53
	Evening peak	10.52	9.24	9.04	5.78
	Off-peak	6.98	7.29	6.75	6.33
5	Morning peak	14.25	14.57	18.88	13.90
	Evening peak	18.11	15.85	15.04	16.98
	Off-peak	14.67	14.02	13.80	14.26
6	Morning peak	—[b]	16.79	—[b]	19.42
	Evening peak	—[b]	20.36	—[b]	17.22
	Off-peak	—[b]	17.93	—[b]	17.09

[a]Vehicles 2 and 20, standard sedans.
[b]The freeway route was not open to traffic in 1962.

the roadway. There are travel time reductions on all routes, although three of the subgroupings for both Routes 4 and 5 show increases in travel time between 1962 and 1968.

Despite the total of 262 test runs made by vehicle 20, when the results are divided into 30 subgroupings, as shown in Table 2, it is inevitable that some of the travel time averages will be based on a small number of runs. It is not appropriate to base final analysis on small sample average travel times. In such cases, the variance of the data is large enough to preclude statistically significant conclusions.

Because vehicles 10, 20, and 30 exhibit maneuverability characteristics of typical passenger vehicles, and because the drivers of these vehicles were given the same driving instructions, i.e., to travel at the same speed as the traffic flow, it was hypothesized that there should not be significant differences in travel times among these vehicles for specific routes, directions, and times. To test this hypothesis, it is necessary to use a test that is appropriate for small samples.

Extensive analysis of vehicle 20 travel times indicated that the data are distributed normally. With sample size as the criterion, there are two tests for analyzing the differences between averages of random samples from normal populations having equal variances. Analysis was performed on the passenger vehicle pairs of (10, 20), (10, 30), (20, 30), and the 90 percent confidence level was used in evaluating the results. No significant difference in travel times among these three vehicles was noted for comparison between the identical subgroupings of averages. Similar analysis for selected subgroupings of travel time averages for vehicles 1, 2, and 3 confirmed this hypothesis for data from the 1962 study.

For refined travel time analysis, travel time data for the passenger-type vehicles were combined. Two composite vehicles were developed: vehicle 100, representing the average of travel time data from test vehicles 1, 2, and 3; and vehicle 200, representing a similar average for vehicles 10, 20, and 30. Travel times for these vehicles are given in Table 3. The primary benefit resulting from combining these averages is that the total of 618 test runs (in 1968) provides a much larger sample and thus a broader basis for data subdivision.

With sample size as the criterion, the student "t" test was appropriate for determining the significance of differences between the travel time averages for morning and evening subgroupings, whereas the "z" test, based on the standard normal distribution, was used for analyzing differences in off-peak averages. Table 4 summarizes the travel

TABLE 3

TRAVEL TIME COMPARISONS FOR PASSENGER VEHICLES

Route	Time of Day	Travel Time in Minutes			
		Northbound		Southbound	
		1962 (100)[a]	1968 (200)[b]	1962 (100)[a]	1968 (200)[b]
2	Morning peak	15.20	12.82	18.86	14.18
	Evening peak	19.11	15.23	14.89	15.30
	Off-peak	13.85	12.89	13.42	13.41
3	Morning peak	33.72	29.82	38.65	30.09
	Evening peak	47.01	38.37	31.59	30.60
	Off-peak	31.97	29.90	31.60	29.41
4	Morning peak	6.72	7.26	6.25	6.44
	Evening peak	10.04	9.41	10.01	7.77
	Off-peak	7.13	7.27	6.83	6.53
5	Morning peak	14.02	14.22	16.20	14.03
	Evening peak	17.82	14.98	15.05	17.40
	Off-peak	13.96	13.95	13.42	14.23
6	Morning peak	—[c]	18.14	—[c]	19.50
	Evening peak	—[c]	25.96	—[c]	17.89
	Off-peak	—[c]	17.76	—[c]	17.29

[a]Composite vehicle 100.
[b]Composite vehicle 200.
[c]The freeway route was not open to traffic in 1962.

TABLE 4

TRAVEL TIME SAVINGS, 1968 VERSUS 1962, FOR ARTERIAL ROUTES ONLY

Route	Time of Day	Time Savings for Composite Passenger Vehicles 100 and 200			
		Northbound		Southbound	
		Minutes	Significance (percent)	Minutes	Significance (percent)
2	Morning peak	2.38	99.5	4.68	99.5
	Evening peak	3.88	99.5	—[a]	
	Off-peak	0.96	99.9	—[a]	
3	Morning peak	3.90	97.5	8.56	99.5
	Evening peak	8.64	99.0	—[a]	
	Off-peak	2.07	99.9	2.19	99.9
4	Morning peak	—[a]		—[a]	
	Evening peak	—[a]		2.24	95.0
	Off-peak	—[a]		0.30	97.5
5	Morning peak	—[a]		2.17	95.0
	Evening peak	2.84	99.0	-2.35[b]	97.5
	Off-peak	—[a]		-0.81[b]	99.9

[a]Indicates subgroupings for which the difference in travel time is not significant at the 90 percent confidence level.
[b]Minus sign denotes an increase in travel time from 1962 to 1968.

time savings for the composite passenger vehicles. With the exception of Route 4, there are significant savings during the peak hours in the peak directions of traffic flow—morning peak hour southbound and evening peak hour northbound.

Increases in travel time are observed on Route 5 southbound during the evening peak and the off-peak periods. In the case of the evening peak, it seems that the increase may be due to traffic engineering changes, specifically an effective signal progression for the benefit of northbound vehicles. There is additional evidence to suggest that Route 5 has not been appreciably affected by the operation of the freeway.

Travel time analysis for the two commercial-type vehicles is inconclusive. Commercial truck operators recognize the difficulties of operation during the peak periods. As a result, these vehicles represent a small portion of peak hour traffic. For this reason, few test runs were made during the 1962 study peak periods, and thus there is no base for comparison of the two periods. However, a general trend of increasing travel time between 1962 and 1968 during the off-peak periods is observed. Using a 90 percent confidence level, there is no difference in travel times between vehicles 4 and 40 on Route 3. Within the same confidence level, there are increases in travel times between 1962 and 1968 for the van truck on Route 2 (off-peak, northbound and southbound) and on Route 3 (off-peak, northbound).

The benefits suggested by Table 4 are correlatable with respect to time with the operation of the Seattle Freeway. However, care must be exercised in interpreting the results, especially when arterial improvements may have contributed to the travel time reduction.

Travel Time Benefits of the Freeway

Without yet evaluating its total extent, the existence of travel time savings on the arterial routes has been verified. In determining the reasons for these savings, which are not due to chance, it is necessary to examine the conditions on the respective routes during the before and after periods. These include traffic volume changes, arterial street improvements, and speed limits. Because these conditions are interrelated with the operation of the freeway, it is first necessary to examine the travel time characteristics on the freeway.

Route 3 provides the most direct comparison with the Seattle Freeway. The routes differ in length by only 1 percent, and their terminal points, for trip analysis purposes, coincide. Route 3 experienced a significant traffic volume reduction after the opening of the freeway. Route 2, which closely parallels a portion of the freeway north of the CBD, also experienced a traffic volume decrease. The freeway section from the Stewart St. off-ramp to N. 85th St. is identical in length to Route 2. The terminal points of this portion of the freeway are within a mile of the terminal points for Route 2.

The traffic volume relief on Route 5 has been very slight. For travel time comparison purposes, Route 5 could be compared with the section of freeway from the Holgate St. overcrossing to N.E. 50th St. The lengths are nearly equal, but because of the spatial separation of the terminal points, the routes do not serve the same traffic demands.

With regard to test Route 4, a 1.8-mile route using a one-way couplet in the CBD, there exists a statistically significant time savings in two of the six time periods. The designation of this route as "US-99-Business" implies that it was the alternate to the parallel section of Route 3 (the Alaskan Way viaduct). The travel time on the comparable section of Route 3 is between a half and a third the travel time on Route 4, depending on the time of day. The north terminal point of Route 4 is located at its intersection with Route 3. The freeway, on the other hand, allows for faster travel (2 minutes versus 7 minutes for Route 4), but the freeway access points do not encourage its use as an alternative to Route 4. As a result, the opening of the freeway had little effect in the diversion of traffic from 2nd Ave. and 4th Ave. and, in fact, has increased the flow of cross traffic.

Table 5 summarizes the travel times for vehicles operating on the arterials in 1962 and on the freeway in 1968. For comparison with Routes 2 and 5, only portions of the freeway are used. The difference between the travel times for the arterial and the freeway represents the time saved by the motorist who elects to use only that length of

TABLE 5

TRAVEL TIME COMPARISONS, FREEWAY VERSUS ARTERIAL

Vehicles	Route	Time of Day	Travel Time in Minutes			
			Northbound		Southbound	
			Arterial	Freeway[a]	Arterial	Freeway[a]
100 and 200	2	Morning peak	15.20	5.31	18.86	6.50
		Evening peak	19.11	7.37	14.89	5.47
		Off-peak	13.85	5.40	13.42	5.40
	3	Morning peak	33.72	18.14	38.65	19.50
		Evening peak	47.01	25.96	31.59	17.89
		Off-peak	31.97	17.76	31.60	17.29
	5	Morning peak	14.02	6.63	16.20	7.47
		Evening peak	17.82	8.72	15.05	6.57
		Off-peak	13.96	6.56	13.42	6.36
4 and 40[b]	3	Morning peak	38.1	20.5	39.0	19.4
		Evening peak	44.6	25.9	(35.9)[c]	19.7
		Off-peak	38.1	20.1	35.9	19.4
5 and 50[b]	2	Morning peak	12.9	5.7	14.9	6.5
		Evening peak	18.0	9.7	15.2	5.9
		Off-peak	12.6	5.7	13.0	5.7
	3	Morning peak	32.0	19.0	35.0	20.6
		Evening peak	33.2	32.2	32.4	19.6
		Off-peak	30.5	18.9	33.0	19.4

[a]Freeway sections used for comparisons are as follows:

Route 2 (5.111 miles northbound, 5.193 miles southbound versus Route 6 from Steward St. to N. 85th (5.10 miles);
Route 3 (16.865 miles) versus Route 6 (16.630 miles);
Route 5 (5.891 miles) versus Route 6 from Holgate to NE 50th St. (5.694 miles).

[b]Truck travel time averages, based on fewer number of runs, have been rounded to tenths of minutes.
[c]Data lacking; off-peak time has been used in calculations.

freeway corresponding to the arterial route. The case of a motorist driving less than the length of the test route will be treated later using volume-averaging techniques. Considering the nature of the test routes, it is inevitable that some motorists will drive for varying distances on extensions of the test routes. Thus, a person living near the northeast city limits may choose to approach Route 2 at its northerly terminal point, or he may enter the freeway at one of the access points between the northern terminal point and the comparable point on Route 2. As a result, the time differential indicated by Table 5 is the minimum time benefit enjoyed.

Statistically, the time savings are all significant, with the exception of vehicle 50 on Route 3 in the evening peak hour traveling northbound. The appreciable size of the other time savings contributes to their recognition by the motoring public and is one of the reasons for the large diversion of traffic to the freeway. Despite the apparent time savings, however, there has been no discernible transfer of traffic from Route 5 to the freeway, probably because Routes 5 and 6 actually constitute two different travel corridors.

Analysis of Traffic Volume Trends

To evaluate the importance of these improvements in travel time, it is necessary to consider the numbers of persons receiving the benefit of the time savings. A problem of this nature is straightforward in the case where the alternate route is abandoned in favor of the new improved route. Unfortunately, this is not the case with the Seattle Freeway. Instead, existing freeway traffic must be viewed as the sum of three basic components: traffic diverted from the arterial routes, traffic resulting from normal growth, and induced traffic, which is not due to normal growth but is attributable to corridor improvements (2). The tremendous impact of this last factor is verified by the fact that, on northern portions of the freeway, traffic volumes in 1967 exceeded the forecast volumes for the design year (1975) by 33 percent.

For volume analysis purposes, Seattle is fortunate to be divided by a natural screenline, the Lake Washington Ship Canal. The canal, connecting Puget Sound and Lake Washington, is crossed by five arterial bridges (24 lanes) and the Freeway Bridge (8 lanes plus 4 reversible lanes). The traffic volumes on these bridges are given in Table 6. The traffic growth rate appears to be small during the pre-freeway years. The only other significant change prior to 1963 is the apparent transfer of some traffic from the Fremont Bridge to the Ballard Bridge in 1962 as a result of arterial improvements on the approaches to the latter bridge.

By 1962, the screenline bridge capacity was being exceeded, with the morning and evening peak periods extending longer than an hour. Some traffic was being diverted to I-405 on the east side of Lake Washington. The heavy directional flow of traffic during the peak periods required the use of reversible lanes (4/2) on the Aurora Bridge as a stop-gap measure. The opening of the section of freeway from Roanoke St. north to Ravenna Blvd. (including the freeway bridge) in December 1962 provided immediate relief to the University Bridge. By 1965, the freeway had been extended southward to the area of the CBD, and volume relief was experienced on the Fremont and Aurora Ave. Bridges. Virtually no change in traffic volumes was observed on the Ballard or Montlake Bridges. The traffic volumes at the Lake Washington Ship Canal screenline are shown in Figure 2.

Using the least-squares technique on the canal screenline volume data from 1958 to 1962, the projected volume in 1968 would have been 261,000 vehicles per day. This figure assumes that arterial improvement would have provided increased capacity, or that the peak periods would be further extended. The operation of the freeway has resulted in 1968 screenline volumes of 339,000. This is 30 percent over the projected volume. Comparing the 1968 and 1962 volumes for the Fremont, Aurora, and University Bridges, it is apparent that a minimum of 60,000 crossings have been diverted to the Freeway Bridge. If the volume growth rate is applied to the 1962 volumes on these three arterial bridges, then 96,000 crossings have been diverted to the freeway. In light of the fact that some arterial traffic is generated, logic dictates that perhaps an intermediate value, 80,000, is representative of the true value of diverted traffic. The portion of the 1968 freeway volume resulting from the accelerated traffic growth is thus 73,000.

The time benefit to the diverted traffic is dependent on the arterial route that formerly carried the traffic. The induced traffic, on the other hand, enjoys a smaller benefit, which at the time of its generation is equal to the difference in travel time between the alternative arterial route and the freeway. For benefit analysis purposes, it is justifiable to assign the generated trips to the possible arterial bridges as follows: University—28,000; Fremont—7,000; and Aurora—38,000. This assignment would adjust the 1968 bridge volumes to the 1962 levels. Further simplification, again for analysis purposes, permits the combination of Fremont and University Bridge assignments,

TABLE 6

LAKE WASHINGTON SHIP CANAL SCREENLINE VOLUMES, 1958-1968

Bridge[a]	24-Hour Total Volume										
	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968
Ballard	31,500	32,500	30,500	38,923	39,458	39,102	38,212	39,929	37,805	39,266	40,300
Fremont	29,500	30,000	34,000	28,315	31,216	28,974	26,918	23,144	29,307	23,260	26,800
Aurora	74,500	81,500	82,500	82,619	79,710	78,958	73,390	54,234	52,429	44,088	45,500
University	44,500	43,000	45,000	44,015	45,630	32,753	22,513	22,513	22,186	21,515	25,600
Montlake	43,000	43,000	42,000	43,029	41,947	41,509	43,402	41,601	42,343	42,682	48,000
Subtotals	223,000	230,000	234,000	236,901	237,961	221,296	204,435	179,282	184,070	170,811	186,200
Freeway[b]	–	–	–	–	–	25,529	50,775	92,872	109,920	141,680	153,120
Total	223,000	230,000	234,000	236,901	237,961	246,825	255,210	272,154	293,990	312,491	339,320

[a]The Ballard Bridge (4 lanes) is 3.0 miles west of the freeway; the Fremont Bridge (4 lanes) is 1.4 miles west of the freeway; the Aurora Ave. Bridge (6 lanes), on Test Route 3, is 1.3 miles west of the freeway; the University Bridge (6 lanes), on Test Route 2, is immediately east of the freeway; and the Montlake Bridge (4 lanes), on Test Route 5, is 0.9 miles east of the freeway.

[b]The Freeway Bridge opened in 1962, although the final sections comprising test section 6 were not completed until 1967.

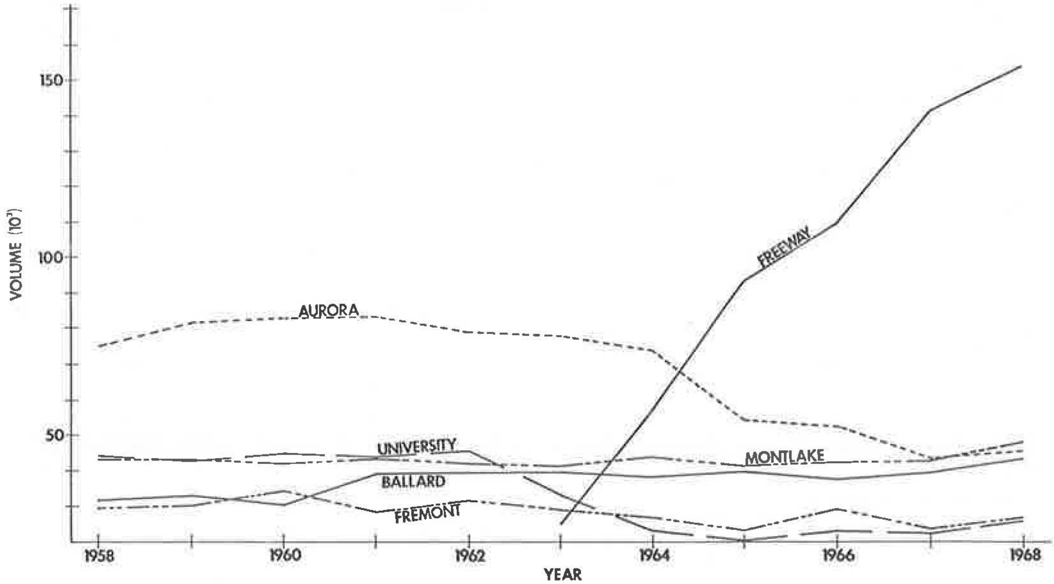

Figure 2. Lake Washington Ship Canal screenline crossings, 1958-68.

because there are several similarities between the traffic on these bridges. This provides a basis for travel time comparisons with data from Route 2. Thus, the 1968 Freeway Bridge volume is made up of the following: crossings diverted from arterials plus growth—80,000; crossings generated, with Route 2 as the alternate—35,000; crossings generated, with Route 3 as the alternate—38,000; and total crossings—153,000.

There are two methods of approaching the time benefit determination. It is possible to evaluate the time savings for each section of the five test routes and multiply this by the section volume. The difficulty in determining the significance of small differences in section travel times suggests that a more realistic approach would be to determine an average test route volume and multiply it by the time savings. This second method was implemented by summing the vehicle-miles of travel on each section of a test route and dividing this figure by the route length. Not unexpectedly, it was found that ratios of annual bridge volumes to 1968 bridge volumes were acceptable factors for developing estimates of route volumes for the years between 1962 and 1967. The average 1968 route volumes developed by this method are, for Route 2—15,900 vehicles per day; Route 3—39,100; Route 4—19,000; Route 5—18,200; and Route 6—117,100. Using these figures, the freeway volumes are interpreted as follows: diverted traffic—61,200; generated traffic, alternate Route 2—26,800; generated traffic, alternate Route 3—29,100.

Additional volume information regarding the percentage of travel during the peak hours was required in order to evaluate the travel time savings for the three time subgroupings used in this analysis. The peak hour travel factors for the routes can be estimated from screenline count data (directional K factors). It must be recognized that the peak periods of traffic flow will occur at different times on the several test routes. There will even be variations in the time of the peak hour at different points along a route. For the sake of uniformity, screenline counts for the hours 7:15-8:15 a.m. and 4:30-5:30 p.m. were defined as the peak hours. The results of the peak hour analysis are given in Table 7. For the detailed analysis, there is no justification for establishing "average K factors" for the arterial and freeway routes. Therefore, the final travel time analysis must utilize each of these individual factors.

Classification counts were taken on Routes 3 and 6, with vehicle groupings established on the basis of the test vehicle types. Foreign cars were included in the compact

TABLE 7

PERCENT OF AVERAGE DAILY TRAFFIC BY TIME OF DAY[a]

(Directional K Factor)

Route	Direction	Morning Peak	Evening Peak	Off-Peak
2	Northbound	6.5	12.6	80.9
	Southbound	10.1	8.2	81.7
3	Northbound	4.5	15.3	80.2
	Southbound	15.6	5.6	78.8
4	Northbound	5.2	7.4	87.4
	Southbound	8.6	7.5	83.9
5	Northbound	7.5	8.3	84.2
	Southbound	7.9	9.3	82.8
6	Nothbound	4.6	12.2	83.2
	Southbound	15.0	6.7	78.3

[a]Data for Routes 2, 3, 5, and 6 are based on 1968 Lake Washington Ship Canal screenline crossings. Data for Route 4 are based on 1968 screenline counts south of Pike St.

TABLE 8

VEHICLE CLASSIFICATION COUNTS, PERCENT

Vehicle Category	Arterial Route 3[a]	Freeway Route 6[b]
Peak Hour, Major Direction		
Compact[c]	17.6	15.8
Sedan	72.1	71.9
Pickup	9.3	10.6
Composite passenger vehicle	99.0	98.3
Medium Truck	0.9	1.0
Heavy Truck	0.1	0.7
Peak Hour, Minor Direction		
Compact[c]	18.9	21.8
Sedan	66.6	63.0
Pickup	9.1	10.4
Composite passenger vehicle	94.6	95.2
Medium Truck	5.3	2.7
Heavy Truck	0.1	2.1
Off-Peak Periods, Both Directions		
Compact[c]	18.4	19.7
Sedan	64.5	65.2
Pickup	10.5	8.8
Composite passenger vehicle	93.4	93.7
Medium truck	5.4	3.0
Heavy truck	1.2	3.3

[a]Route 3, Aurora Ave. N. at Comstock.
[b]Route 6, Seattle Freeway at Roanoke.
[c]Compact classification includes both foreign and compact vehicles.

group, under the assumption that their travel times would not differ significantly from the travel times for the compact vehicle, which in turn are identical with those for the sedan and pickup truck, as summarized in the data for the composite passenger vehicle. The results of the vehicle classification survey are given in Table 8. It can be seen that the composite passenger vehicle constitutes between 93.4 and 99.0 percent of the traffic. In extending these results to the other arterial routes, it is assumed that no heavy trucks (i.e., vehicles 4 and 40) use Routes 2, 4, or 5, and that medium trucks (i.e., vehicles 5 and 50) will not operate on Routes 4 or 5.

The evaluation of time savings on each route is in essence a matrix multiplication process, using the previously presented data as elements. The procedure can be summarized as follows:

$$B_{k,a} = U\,(V_{1i})\,(P_{ij})\,(T_{i1})$$

where

$B_{k,a}$ = time benefit per day on Route k for vehicle a;
U = a scaler, equal to one-half the route volume;
V = a 1x6 matrix whose components are the vehicle classification percentages;
P = a 6x6 diagonalized matrix whose nonzero components are the respective peak hour travel factors;
T = a 6x1 matrix whose elements are the time saved by vehicle on a route; and
i,j = subscripts of time subgroupings (e.g., $i = 1$ for morning peak hour northbound; $i = 2$ for evening peak hour northbound; . . .; $i = 6$ for off-peak southbound).

This procedure could be extended, using larger matrices to provide the total benefit in one calculation. Because this phase of the analysis was not computerized, the extended procedure was not used.

In evaluating the benefit for traffic currently using the freeway, a slightly more complex procedure, recognizing the difference in benefits between the diverted and generated traffic, must be used. The time saving for diverted traffic is actually equal to the difference in travel time between the improved condition (1968 with freeway) and the condition that would have existed if the freeway had not been built (1968 arterial with no freeway). The latter condition does not exist and therefore is not measurable. It is conservatively approximated by the 1962 arterial travel time. The generated traffic for the year 1968 enjoys a travel time benefit equal to the difference between the freeway and arterial travel times in 1968. Lacking other information, it is assumed that the peak hour factors and the vehicle classification factors are the same for the diverted and generated traffic.

Two additional factors were developed, one for the freeway and one for the arterials, to convert the average daily traffic into annual volumes and to simultaneously convert the result from minutes per day to hours per year. The annual savings in hours for the various types of vehicles are given in Table 9. The effect of diverting traffic from the arterials has already been discussed. There is good cause to ascribe the concommitant arterial savings in travel time to the category of freeway benefits. However, the travel time changes on Routes 4 and 5 are definitely not due to freeway operation, but rather have resulted from arterial improvements, such as signal progression and parking and turning restrictions.

Conversion to Monetary Terms

In interpreting the financial significance of Table 9, consideration must be given to two supplementary pieces of information: vehicle occupancy and the value of time. The value of the former is easily approximated from data gathered in urban transportation studies or other special studies. For the test routes studied, values of 1.5 persons per vehicle on arterials and 1.3 persons per vehicle on the freeway can be used. These values represent averages, but their reasonableness has been verified by spot studies conducted at various points along the routes. They are also in accordance with generalized results published by the Puget Sound Regional Transportation Study (3).

It is not within the scope of this study to develop a value of time. Rather, based on the research by others, the task is to select appropriate time values and apply them to the data given in Table 9. Such a process must, of course, consider the variable time values associated with various trip purposes.

Values of time savings to commercial vehicles have been established by Adkins, Ward, and McFarland (4). Table 35 in their report (4) lists the 1965 values of time savings components (interest, wages, etc.) for 18 cargo vehicle types operating in the Pacific (ICC) Region. Adjusting the values to 1968 at a growth rate of approximately 5 percent per year provided the following information:

Vehicle 40	3S2, diesel, light, van	$7.20 per hour
Vehicle 50	S. U. 2-axle, gasoline, van	$4.77 per hour

With respect to passenger vehicles, a study at the Stanford Research Institute (5) found the average time value to be $2.82 per person per hour. This value is in accord with the research of others (6). There is little hesitancy in applying this value to commuting motorists, who were in fact the sources of information for these studies. The group of noncommuters, who make up the bulk of traffic in the off-peak hours, is not correctly represented by this figure, however. Those persons who are traveling during working hours most certainly have a higher value associated with their companies' time, whereas others such as shoppers may

TABLE 9

TIME BENEFIT

Vehicles	Route	Time Saved, Vehicle Hours per Year: Due to Freeway	Due to Other
100/200	2	84,300	–
	3	673,400	–
	4	–	23,000
	5	–	-25,400
	6	7,626,100	–
Total		8,383,800	-2,400
4/40	3	0	–
	6	328,600	–
Total		328,600	–
5/50	2	-6,600	–
	3	-16,600	–
	6	179,400	–
Total		156,200	-2,400

value their time less. Hypothesizing that 40 percent of the daily traffic is composed of commuters (at $2.82 per hour), that 20 percent are traveling during working hours (at $4.00 per hour), and that 40 percent are persons making nonwork trips (at $1.40 per hour, average), then the composite value of time would be $2.50 per person per hour (3).

By the nature of the problem, this value is difficult if not impossible to verify. Certainly, it represents a reasonable value. It is in accord with the toll paid by motorists on a toll bridge in the Seattle area. This value provides a method of transforming the benefit coordinates to a system where they are more recognizable.

The application of these values to the time savings provides an answer in monetary terms. The values obtained for the year 1968 are as follows: passenger vehicles—$27,626,000; commercial vehicles—$3,111,000; and total time benefit—$30,737,000. To provide a frame of reference, this amount is 12 percent of the total construction costs for Route 6. It should be noted that the staggered opening of the freeway prior to 1968 would have severely limited the size of previous benefits. Similarly, the benefit in coming years will be decreased as volumes and travel times increase. Any conclusion that the freeway will "pay for itself" in travel time savings alone in 8 or 9 years must be immediately rejected.

ANALYSIS OF VEHICLE OPERATING COSTS

Despite the overwhelming amount of the apparent savings in travel time, the freeway may also provide a sizable benefit by reducing the vehicle operating costs incurred in making a trip. However, there is little current information comparing the costs between freeways and arterials. This portion of the paper will develop a methodology for comparing vehicle operating costs and, based on the data gathered in the study, will evaluate the net benefit in fuel savings resulting from freeway operation.

Fuel Consumption Analysis

There are two major problems associated with the analysis of fuel consumption: the measurement of data and the separation of changes resulting from improvements in vehicles and fuel from those changes resulting from highway improvements. The former problem was solved by using the fuel meter and the burette board, as discussed previously. Although only minor recognition has been given to the fuel meter, it is recognized that the accuracy of fuel consumption data for passenger vehicles obtained in this study would not have been possible without it.

The second problem is related to the impact that nonmeasured elements may exert on the analysis. If an improvement in the fuel consumption rate is observed, it is important to identify the cause of the improvement. Consideration must be given to the quality of the fuel, for example. Although it is common knowledge that the fuel octane rating has continued to increase in recent years, it is not generally recognized that this has virtually no effect on fuel consumption. The internal energy of fuel, which has remained relatively constant, is more closely related to fuel use. The improvements brought about by fuel additives are real, but appear to be minor in comparison with other variables.

However, vehicular changes can have a significant effect on fuel consumption. The combustion process may be made more efficient, rolling resistance can be reduced, drive train efficiency can be improved, and so forth. It is not feasible to analyze each possible improvement separately. Rather, the net result of fuel and vehicular improvements can be measured by determining the fuel consumption of the test vehicles at constant speeds. For this purpose, Test Route 7, a 12.8-mile section of Interstate Freeway south of Seattle, was used for vehicle calibration. The vehicles were driven at a series of constant speeds in both the northbound and southbound directions. The vehicle speedometers served as a guide to the drivers in maintaining a constant speed. Actual overall speed was computed from the travel time recorded by the observer. The fuel data—counts on the FM 201 for the fuel meter and milliliters for the burette board—were adjusted for the effect of temperature and were summarized in gallons, miles per gallon, and gallons per mile. Because of the difficulty of averaging fuel consumption in miles per gallon, final fuel analysis was based on the average gallons of fuel used.

The data from the series of vehicle calibration runs are given in Table 10. For the low-speed runs with vehicles 10 and 20, there is some doubt that the automatic transmission shifted into high gear. This is unfortunate, because in the analysis process there is a need to interpolate the fuel consumption rate at speeds in the 20- to 30-mph range.

The results of the calibration testing of the passenger-type vehicles indicate that there is a definite improvement in fuel consumption rates at constant speeds for the 1968 test vehicles compared to the 1962 test vehicles. The improvement is greatest in the range from 25 to 40 mph. It tapers off at both higher and lower speeds.

The calibration data for vehicles 2 and 20 are shown in Figure 3. For these vehicles, the maximum improvement of 21 percent is realized at a constant speed of 35 mph. The improvement at 70 mph is only 7 percent. These improvements are due to the previously mentioned vehicular and fuel differences.

The calibration curves can be used to assign the changes in fuel consumption to two separate causes—vehicular and fuel improvements, and highway improvements. The procedure used is to develop a factor relating the two calibration curves at a given speed. To facilitate subsequent calculations, the fuel factor was defined as

$$f(x) = \frac{\text{1968 vehicle calibration curve in MPG at speed x}}{\text{1962 vehicle calibration curve in MPG at speed x}}$$

where f(x) is the fuel factor at speed x and MPG is miles per gallon.

The fuel factor converts the gallons of fuel used by a 1968 test vehicle into the number of gallons that would have been used by the corresponding 1962 test vehicle if the latter were used in the after study. The 1968 test vehicle enjoyed the benefit of decreased travel time and improved smoothness of traffic operation. The magnitude of this benefit is given by the difference between the adjusted 1968 fuel consumption and the fuel consumption measured in 1962. In most cases, the before and after travel speeds are not equal. The calibration curve accounts for this fact by providing the factor that adjusts fuel consumption to the 1968 speed. The 1968 speed is used because that is the speed at which the 1962 vehicles would have operated in the after study.

Obviously, the variations in fuel consumption characteristics among the several test vehicles preclude the use of a composite vehicle. However, for each vehicle it is possible to combine the data from several time periods. Analysis was based on three time subgroupings:

1. Northbound morning peak hour and southbound evening peak hour (direction of minor traffic flows);
2. Northbound evening peak hour and southbound morning peak hour (direction of major traffic flows); and
3. Northbound off-peak and southbound off-peak.

There are several advantages associated with this method of analysis. The peak hour screenline counts showed that the percentage of average daily traffic occurring during the two time components of subgroup 1 are comparable. The same equivalence is shown by the components of subgroups 2

TABLE 10

FUEL CONSUMPTION RATES AT CONSTANT SPEED ON TEST ROUTE 7

Vehicles	1962 Average Speed (mph)	1962 Fuel (mpg)	1968 Average Speed (mph)	1968 Fuel (mpg)
1/10	18.335	23.553	19.247	(22.368)[a]
	28.907	21.659	28.777	33.277
	38.607	21.504	38.124	26.006
	48.291	20.189	48.086	23.949
	56.407	16.574	57.907	21.387
	66.210	14.022	68.225	20.554
2/20	19.767	19.573	20.533	21.352
	29.635	19.386	31.424	23.096
	39.053	18.557	41.745	22.359
	49.001	17.467	51.732	19.156
	58.760	16.141	60.844	17.570
	69.240	14.328	70.674	15.589
3/30	30.233	22.879	32.172	26.504
	38.925	20.763	39.608	24.978
	49.164	17.527	50.875	21.531
	59.213	14.826	59.054	18.816
	69.069	11.771	69.664	13.946
4/40	29.265	6.273	29.892	7.081
	38.881	6.578	39.995	7.410
	47.735	6.315	48.504	7.231
5/50	31.825	9.341	28.486	9.791
	41.968	10.055	37.878	8.430
	52.136	7.693	47.338	7.048
			57.387	5.640

[a]It is quite possible that vehicle 10 was not operating in high gear at 20 mph.

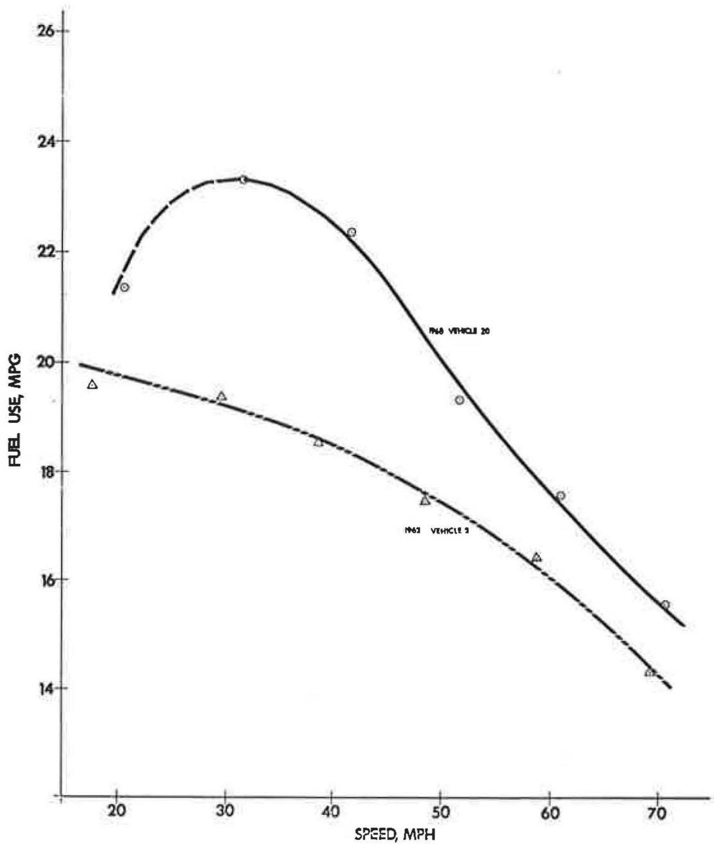

Figure 3. Fuel use comparison of standard vehicle, 1962 and 1968.

and 3 respectively. In addition, the topography of Seattle is such that the southbound trips consistently enjoy better fuel mileage than the northbound trips. This method permits analysis on a round-trip basis, thus minimizing the influence of topography. It should be noted that this subdivision of the data represents a combination of the travel time subgroupings.

The analysis is similar to the travel time computations in the sense that there are two types of benefits: those accruing to persons who continue to use the arterials, and those accruing to freeway users whose alternate route would have been Route 2 or 3. The improved operating conditions provided by the freeway are in part counterbalanced by the poorer fuel economy obtained at higher freeway operating speeds.

The development of fuel comparisons for vehicles 2 and 20, which represent by far the largest segment of the vehicle population, is given in Table 11. Analysis is not shown for Route 4 because the low travel speeds on this route lie outside the range of applicability of the calibration curves. In addition, the minor traffic volume relief experienced on this route suggests that any improvement in operation is not due to the freeway.

For the standard sedan, there are significant fuel savings for the peak hour traffic in the major direction of flow on Routes 2 and 5. The actual savings in gallons are quite small, however. A comparison of fuel consumption between the freeway and the alternate arterial routes indicates a definite user benefit for persons driving standard sedans. A commuting motorist could save up to $1\frac{1}{2}$ gallons of fuel per week by using the freeway.

TABLE 11

FUEL CONSUMPTION COMPARISONS FOR VEHICLES 2 AND 20

Route	Time Subgroup[a]	1968				1962 Fuel[c]	Fuel Savings[c]	Percent Savings
		f(x)	Speed[b]	Fuel[c]	Fuel, adj.[c]			
2	1	1.12	22.7	0.2736	0.306	0.321	+0.015	4
	2	1.07	21.1	0.2868	0.306	0.363	+0.057	16
	3	1.13	23.5	0.1819	0.320	0.320	0	0
3	1	1.20	32.2	0.8388	1.011	0.957	-0.054	-6
	2	1.20	30.8	0.8557	1.029	1.052	+0.023	2
	3	1.21	34.4	0.8379	1.012	0.993	-0.019	-2
5	1	1.11	22.4	0.3699	0.411	0.396	-0.015	-4
	2	1.14	23.8	0.3385	0.386	0.439	+0.053	12
	3	1.16	25.0	0.3339	0.387	0.395	+0.008	2
6 (Alt. 2)[d]	1	1.10	60.2	0.2380	0.262	0.321	+0.059	18
	2	1.17	48.9	0.2257	0.263	0.363	+0.100	27
	3	1.12	57.2	0.2361	0.264	0.320	+0.056	17
6 (Alt. 3)[e]	1	1.11	58.7	0.7903	0.876	0.957	+0.081	8
	2	1.16	50.2	0.7692	0.891	1.052	+0.160	15
	3	1.12	57.0	0.8054	0.899	0.993	+0.094	9

[a]1 indicates average of northbound morning and southbound evening; 2 indicates average of northbound evening and southbound morning; 3 indicates average of northbound off-peak and southbound off-peak.
[b]In miles per hour.
[c]Fuel measured in gallons.
[d]Section of freeway from Stewart St. to N. 85th St.
[e]Entire length of Route 3.

The success achieved in the area of fuel consumption analysis for vehicles 2 and 20 was unfortunately not duplicated in the comparative analyses of the compact sedan and the pickup truck. There are several reasons for the shortcomings. Primarily, there is a minimal amount of data for these types of vehicles in the peak periods in the 1962 study. Vehicles 2 and 20 made more peak hour runs (excluding Route 4) than did vehicles 1, 3, 10, and 30 combined. This problem was circumvented in the travel time analysis by the uniformity of the data and the development of the composite vehicles. Also, vehicles 1 and 10 should have had identical calibration curves because they were virtually identical vehicles. However, vehicle 10 achieved up to 46 percent better fuel mileage on the calibration section. On Test Routes 2, 3, and 5, the unadjusted fuel consumption was not statistically different from that of vehicle 1. Because of the conflicting fuel data, it is not possible to make statistically significant statements about the possible nature of fuel consumption benefits for compact vehicles.

Vehicle 30, the 1965 pickup truck, demonstrated similar inconsistencies, although they were not as pronounced as for vehicle 10. The only increase in fuel consumption on arterials that is significant is on Route 2, period 3. A comparison of fuel consumption for Route 6 versus the two alternate routes indicated an average increase in fuel consumption during period 3. The results for vehicle 30 suggest that, for a pickup truck with a 6-cylinder engine, the increased fuel consumption at freeway speeds is not wholly balanced by the improvement in smoothness of operation.

The analysis of truck fuel consumption was simplified by the fact that professional truck drivers drive in a consistent manner. As a result, meaningful analysis can be performed on the comparatively small number of off-peak runs. Because of the small variance of the data, some changes in fuel consumption of 10 percent were significant at the 95 percent confidence level. On this basis, there was no benefit for vehicle 40 on Route 3, but there was a positive benefit for the freeway compared to Route 3. On the other hand, vehicle 50 used significantly more fuel in off-peak comparisons of the arterials and the freeway. The reasons for the unusual results for vehicle 50 are not intuitive.

The most reasonable explanation is that the calibration curves do not represent the relative fuel consumption under normal traffic conditions. As a result vehicle 50, which has 30 percent more horsepower and 10 percent more engine displacement than vehicle 5, does not display similar fuel consumption characteristics. On the other hand, vehicle 50 is more typical of the van trucks on the road in 1968 than is vehicle 5. The trend is toward more powerful trucks with larger engines. Apparently, the trucking industry feels that the poorer fuel consumption achieved by these vehicles is more than accounted for by the increased range of service they provide.

The statistically significant changes in fuel consumption are summarized in Table 12. Because of the problems associated with the fuel data from vehicle 10, it was not possible to evaluate the significance of the changes in fuel consumption for this vehicle. The standard sedan shows a notable improvement on the freeway, with minor improvements on the arterial routes. Vehicle 40, the diesel truck, has an unexpectedly high fuel savings on the freeway, although it consumes fuel at the rate of 6 to 7 miles per gallon.

The total amount of fuel saved is calculated by a method similar to the matrix procedure used for travel time analysis. The decreases in fuel consumption were included as negative benefits. Peak hour percentages were regrouped to correspond to the revised time subgroupings. With this basis, the following fuel savings in gallons per year were established:

Category	Gasoline	Diesel
Arterials	-318,000	—
Freeway	1,560,000	458,000
Net benefit	1,250,000	458,000

It is difficult to define the average cost of fuel. A gasoline price war in an urban area may cause prices to change drastically. A drop in price from 33 cents per gallon to 30 cents per gallon, an apparent 10 percent reduction, is actually an 18 percent reduction if the fuel tax (9 cents per gallon state tax and 4 cents per gallon federal tax) is subtracted from the price. Of course, for analysis purposes it is mandatory that the tax be subtracted from the cost. The fuel tax is not an inherent part of fuel costs. Rather, it represents the simplest and perhaps the most equitable method of highway user taxation.

Returning to the question of fuel price, a spot study of advertised fuel prices at major brand stations in the Seattle area on a day during the study discovered a range of 33.9 to 37.9 cents per gallon for regular gasoline. Within the past year, these prices have dropped as low as 29.9 cents per gallon. The prices for premium grade gasoline are normally 3 to 4 cents per gallon more than the regular grade.

A study of consumer awareness of motor fuel prices by Cook (8) found that at the moment of purchase only 50 percent of Virginia drivers knew within 1 cent the price they were paying for gasoline. Motorists buying economy or regular grades of gas were no more price-conscious than those purchasing premium gas. Among those who were aware of the price, only 26 percent cited cost as a factor in their choice of fuel. Manufacturer's recommendations or engine requirements were often given as the reason for selecting a grade of fuel. Based partially on these results, an average Seattle area fuel cost of 35 cents per gallon was selected. This value accounts for the costs of the various grades and also for price fluctuation. This cost must be reduced by the 13 cents of federal and state fuel taxes. Thus, the value for analysis purposes is 22 cents per gallon. It should be remembered that this cost is a variable from

TABLE 12

SUMMARY OF SIGNIFICANT FUEL CONSUMPTION BENEFITS[a]

Route	Vehicle	Time Subgroup	Fuel Savings per Vehicle (gallons)
2	20	2	0.057
	30	3	-0.056
	50	3	-0.313
3	50	3	-0.414
5	20	2	0.053
6(Alt. 2)	20	1	0.059
		2	0.100
		3	0.056
	30	3	-0.060
	50	3	-0.173
6(Alt. 3)	20	1	0.081
		2	0.160
		3	0.094
	30	3	-0.234
	40	3	0.435
	50	2	-0.254

[a]No changes attributable to the freeway were found on Route 4. The improvement for vehicle 20, Route 5, time period 3, was due to arterial improvements.

place to place. The price of diesel fuel is slightly less, depending on the grade and, in some cases, the quantity bought. For diesel fuel analysis, a cost of 20 cents per gallon is used. This value is intended to represent an average of the generally lower cost of diesel fuel and the quantity discount given to trucking firms.

Applying these costs to the number of gallons saved produces a total benefit in 1968 of $366,000. Of this benefit, $91,000, or 25 percent, is realized by the diesel trucks. The apparent negative fuel benefits for the pickup and van trucks cut sharply into the net benefit.

In comparison with the travel time benefit of $30 million annually, the savings on fuel is almost negligible. Although it does exist, it is probably not noticed by the general public. The weekly fuel savings for the sedan is approximately 1 gallon if 5 round trips per week are made on the freeway. The actual net benefit is, of course, the result of a summation of incremental savings accruing to individual users.

In a sense it is unusual that a fuel savings was realized. Despite the high rate of fuel consumption at freeway speeds, as indicated by the calibration curves, the freeway benefit actually results from a comparison of fuel use at constant speeds versus the fuel use under stop-and-go conditions on arterials. Because of the sensitivity of fuel consumption to operating conditions and to topography, it may be difficult to duplicate these results at another point.

In analyzing the fuel data, several unsuccessful attempts were made to establish a relationship between fuel consumption and other variables on which information was available. These approaches are worthy of note because their negative results may provide a guideline for subsequent research.

It was suggested that a relationship might exist between test route overall speed and fuel consumption. For the arterial test routes, no significant correlation could be established between these two variables. However, plots of the freeway data, as might be expected, follow the trend of calibration curves. On section 6 of the freeway (Stewart St. to the Freeway Bridge), fuel consumption was actually less than on the calibration section at the same speed. This does not impair the integrity of the calibration curves, however, because they do not define an absolute fuel consumption, but rather provide a basis for comparison of vehicles under identical conditions.

An analysis of fuel consumption for specific runs, as related to actual 15-minute traffic volumes at the times the runs were made for a section of the freeway, proved to be inconclusive. A general trend of decreasing fuel consumption with higher volumes was discernible, but the data were not consistent enough to permit meaningful conclusions to be drawn.

The logical conclusion from the fuel analysis portion of the study is that positive benefits in the area of vehicle operation costs can result from freeway operation. Special attention has been devoted to fuel consumption, although it is conceivable that there may be concurrent savings in oil and tire costs and possibly vehicle maintenance costs. Additional variables, specifically the quality of oil and tires used, suggest that a meaningful study of the benefits associated with these items would be quite difficult.

SUMMARY

Of the two components of highway user benefits that have been analyzed, the time savings benefit is by far the largest in magnitude and the most obvious to the road user. The fuel savings benefit, although small, is perhaps realized by groups of persons within our polarized society that have simultaneously embraced the concepts of the economical (foreign) car and the luxury of the high-powered vehicles. There is a great deal of evidence to suggest that the public is not concerned about saving a few cents worth of fuel. On the other hand, there is an apparent obsession among many users to minimize the amount of travel time required for making a trip. The impact of these factors on the analysis is virtually nonexistent, however, as they merely add insight in interpreting the results.

If the highway engineer is concerned with the optimization of user benefits resulting from urban freeway construction and operation and the justification of capital expenditures on the basis of these benefits, this study would indicate that, in the case of urban freeways, the analysis of benefits might well be concentrated in the area of travel time savings. A supplementary report indicates that the accident reduction benefit for an urban freeway may be significant, although on a per-vehicle-mile basis it is less than 10 percent of the time savings benefit.

Although the annual time savings benefit exceeds $30 million, an amount exceeding the annual freeway cost, there is some doubt that the net non-user benefits that have resulted from freeway operation are characterized by a negative value and thus may distract from the total benefit. Although it was not within the scope of this investigation to evaluate indirect benefits, their monetary importance could easily exceed that of fuel savings. Therefore, before detailed evaluation of this form of user benefit is undertaken, consideration should also be given to other benefits of comparable size.

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