United States
Environmental Protection
Agency

Region 10
1200 Sixth Avenue
Seattle WA 98101

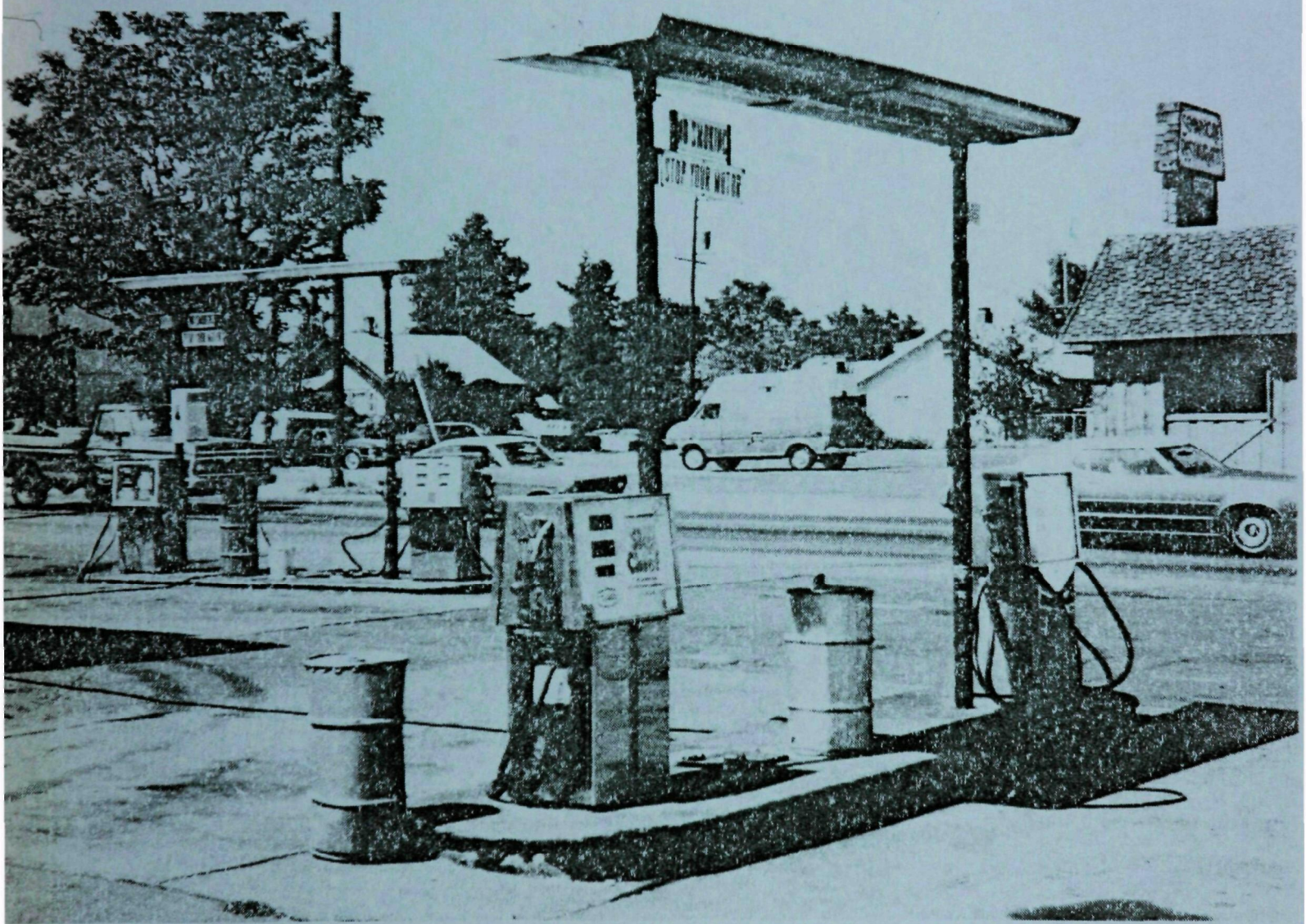
Air

EPA 910-9-80-078

EPA

Incidence of Automobile Fuel Switching in the Pacific Northwest

1979



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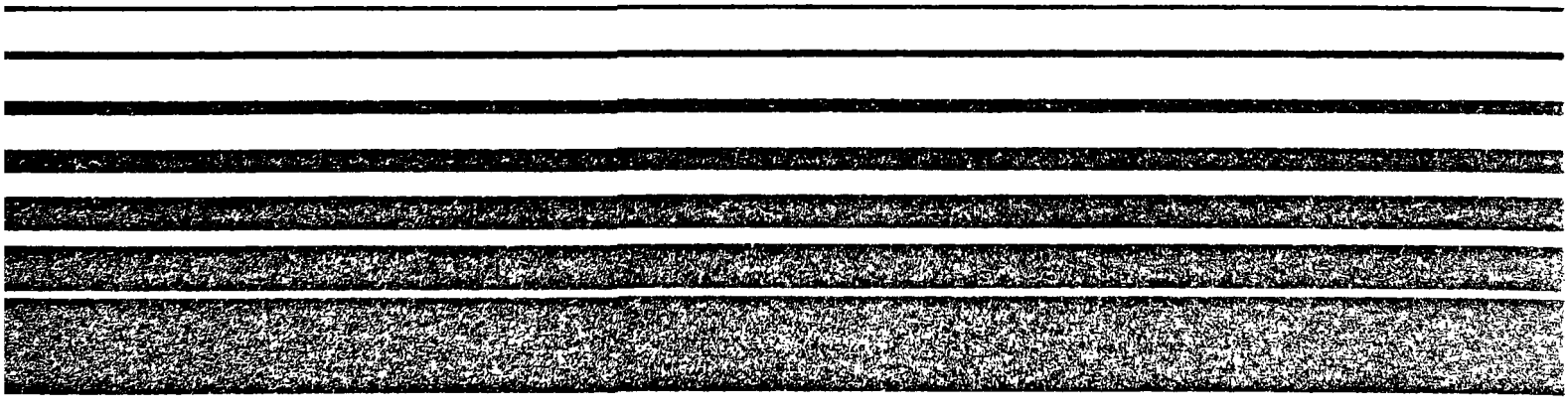

EPA 910/9-80-078

INCIDENCE OF AUTOMOBILE FUEL SWITCHING IN THE PACIFIC NORTHWEST

by

W. Douglas Smith
Surveillance Branch

ENVIRONMENTAL PROTECTION AGENCY
REGION X
SURVEILLANCE & ANALYSIS DIVISION
1200 Sixth Avenue
Seattle, Washington 98101

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ABBREVIATIONS AND SYMBOLS

DMV	Department of Motor Vehicles
TSC	Technology Service Corporation, EPA's statistical methodology contractor.
EPA	Environmental Protection Agency
MSED	Mobile Sources Enforcement Division
QA	Quality Assurance
I&M	Inspection and Maintenance Program
"A"	Symbol used to signify that an alternate gasoline station was observed when the scheduled station was closed to the general public.
P	Symbol used to signify leaded premium gasoline.
PU	Symbol used to signify unleaded premium gasoline.
R	Symbol used to signify leaded regular gasoline.
RU	Symbol used to signify unleaded regular gasoline where a leaded regular grade was unavailable; as found in some Union Oil stations.
UL	Symbol used to signify unleaded gasoline.

INTRODUCTION

National health standards for carbon monoxide, nitrogen dioxide, and ozone are presently being exceeded in many cities throughout the nation, including several in the Pacific Northwest and Alaska. Motor vehicles contribute nearly 82% of the total amount of carbon monoxide found in the urban atmosphere. They also emit over 42% of the hydrocarbons and nearly 44% of the oxides of nitrogen, two major causes of ozone (EPA 1974-75).

Through the Clean Air Act and its subsequent amendments, the U.S. Government has placed various restrictions on motor vehicle emissions since 1963. The Clean Air Act amendments of 1970 and 1977 required further vehicle emission requirements, such as the development of air pollution control strategies by the state pollution control agencies through State Implementation Plans. Under the amendments, the automobile industry developed their own technology for reducing these emissions. The U.S. and some foreign automobile manufacturers chose the catalytic converter as a control device. The catalytic converter, which requires the use of unleaded gasoline, was first installed on some 1975 model year automobiles. Since that time, most new automobiles were equipped with catalytic converters. The amendments prohibit tampering with motor vehicle emission controls by businesses engaged in repairing, servicing, leasing, or selling motor vehicles. To insure the use of unleaded fuel, retail gasoline stations, fleet operators, service centers, and wholesale distributors were prohibited from fueling the vehicles designed for unleaded fuel (those having catalytic converters) with leaded gasoline. Additional safeguards were added to the vehicles and the unleaded gasoline pumps to insure compliance with the Act.

However, neither the Act nor subsequent regulations addressed tampering by individual auto owners. Some states have laws which prohibit tampering by individuals, but few are adequately enforced.

The Environmental Protection Agency is responsible for assuring compliance with the Act by monitoring and enforcing where violations resulting from fuel switching and unleaded fuel contamination exist. During the course of routine service station inspections, it was noted that in spite of prohibitions concerning the introduction of leaded fuel into automobiles designed for unleaded fuel, varying degrees of fuel switching were observed at many of the gasoline service stations.

EXECUTIVE SUMMARY

The Surveillance & Analysis Division of EPA Region X, Seattle, Washington has completed a survey which was designed to: (1) assess the relative percentage of fuel switching in the six major urban centers within EPA Region X (Alaska, Idaho, Oregon, and Washington), (2) establish both quality assurance and statistical methodology for field observation and evaluation of fuel switching data, and (3) determine possible motives for switching such as price, octane level, or gasoline brand.

During the period April to September, 1979, approximately 9,000 vehicles were observed refueling in six cities throughout the Region, excluding Alaska. Alaska did not represent a significant vehicle population. Of these 9,000 vehicles, 3,000 were identified as requiring unleaded gasoline. The fuel requirements for another 1,600 vehicles could not be identified for various reasons (Table 4).

The cities of Boise, Eugene, Portland, Seattle, Spokane, and Tacoma were chosen, because they represented the major population centers where air quality problems related to vehicle emissions had been identified. Vehicles were observed while participating in routine refueling operations at randomly selected gasoline stations. The stations were selected so that observations reasonably represented the total population of vehicles and fueling practices for each specific city studied.

Employees of the Surveillance Branch of the Surveillance & Analysis Division of Region X worked with an experienced consultant (Technology Service Corporation). This consultant was used in close collaboration in

each city to assure consistent application of predetermined study criteria. A total of 432 service stations were observed with an average of 21 vehicles monitored at each station. Observation periods were statistically set to average 1.5 hours per station.

The proportion of all service station visits by catalytic-converter-equipped vehicles in the urban area during the observation period that resulted in the purchase of leaded gasoline (fuel switching) is defined as "R*". The R* can be estimated as a statistical mean with 95% confidence intervals from the observed service station visits. Table 1 shows the estimated fuel switching for each city studied.

Table 1

Fuel Switching Rates

City	R* Estimate (% of fuel switching)
Boise	18.1
Eugene	8.4
Portland	6.0
Seattle	7.0
Spokane	7.3
Tacoma	4.8

With the exception of Boise, there was no significant difference between the fuel switching rates in any of the remaining five urban areas. The average fuel switching rate for these five areas was R* = 6.9%. This survey included a comprehensive field methodology compatible with strict statistical techniques to determine R* and 95% confidence intervals.

Finally, the effects of the following service station characteristics were analyzed; location, price differential, type of service, and trade name. Although no statistically valid conclusions were reached, the overall qualitative conclusions that might indicate parameters for further examination are:

1. There was strong evidence that the degree of fuel switching depends on the city under study, or at least that Boise is different from other cities within Region X.
2. There is weak evidence that, in addition, the proportion of switchers is higher at self, rather than full service stations.
3. At the time of the study, there was no evidence that price difference or major/minor trade name classification played a role. A substantially larger, carefully stratified survey would be needed for further analysis. The 1979 fuel shortage may have made gasoline availability more important than price, octane, brand, or any other factor.

METHODOLOGY

The methodology for this study was jointly developed by regional office staff, representatives from EPA's Mobile Source Enforcement Division (MSED), a statistician from EPA's Planning and Management Office, and a contractor-consultant represented by Technology Service Corporation of Santa Monica, California. The field, data handling, and quality assurance (QA) procedures were agreed upon by MSED, the consultant, and the regional office staff. Methodology was divided into the survey design, field methods, and quality assurance procedures.

Meeting the objectives of the study was complicated by a fuel shortage which occurred during the period of the survey. Field methods had to be subtly altered on a continuous basis because of irregular gasoline availability requiring greater coordination so that results would remain statistically valid.

Survey Design:

Six urban areas were chosen to be studied in Region X on the basis of representative population and violations of air quality standards for pollutants related to vehicle emissions. These cities were Seattle, Spokane, Portland, Tacoma, Eugene/Springfield, and Boise. Portland is unique, in that it is the only city in this study with a vehicle inspection and maintenance program (I&M). The I&M program is operated by the Oregon Department of Environmental Quality under EPA guidelines. The metropolitan area of Eugene/Springfield, Oregon was selected for

comparison to Portland since National Ambient Air Quality Standards are exceeded there also, but that area does not have an I&M program.

In each of the cities, the purpose was to estimate the fraction of catalytic-converter-equipped vehicles that were using leaded gas. The study design was to select a representative number of service stations listed in the telephone directory yellow pages of each study area using statistically defensible procedures, and to observe motor vehicle filling operations at each location. Detailed survey design procedures are presented in Appendix A (Breiman, 1979).

Field Methods:

Only trained observers were used. Control and coordination was provided by a field supervisor. Observers positioned themselves close enough to the fueling operations to gather accurate data without creating suspicion or altering the normal activity of the station. The team developed innovative observation techniques for a wide variety of circumstances.

A Field Observation Form was supplied that contained information about the time, location, trade name, price per gallon, vehicle license numbers, make, model, and type of vehicle, service category, and whether the fuel was premium, leaded, or unleaded (Appendix B). Each form also indicated a unique station identification number. On the back of the form, the observer would construct a map or diagram of the station describing the location of the offices, garages, and pump island configuration.

The individual pumps were marked and identified a P (Premium), PU (Premium-unleaded), R (Regular), RU (Regular-unleaded), UL (Unleaded), or D (Diesel) on the diagram. RU designated that no regular leaded exists, as in Union stations in Washington and Oregon. If it was impossible to determine the type of gasoline initially, the pumps were numbered and later the type of gasoline was noted and recorded correspondingly.

The observation period for each station was set at 1.5 hours. There were circumstances when it was impossible to continue the observation, and a shorter time resulted. As long as a minimum of 0.5 hours was completed, the remaining time could be pro-rated to 1.5 hours based upon the vehicles already observed before leaving the site. Pro-rating was used on less than 5% of the observations and did not significantly alter the statistical procedure or results.

If the assigned station was closed, out of gas, or restricted in consumer service (i.e., commercial vehicles only), it was agreed that a nearby station could be substituted. However, every effort was made to observe the original designated station, even if it obviously had a much lower volume than nearby stations. If selection of a nearby alternate was necessary, the field form identification number for the designated station was given an "A" to signify "alternate" station. Alternate "A" stations were considered as the same as the designated stations. This procedure was necessary as the result of the 1979 gasoline crisis, and was under the close coordination of the field leader and consulting contractor from Technology Service Corporation.

Quality Assurance:

Quality assurance procedures were considered critical to the validity of this study. Specific attention was given to the following study areas where error was most likely to occur: (1) identifying and recording license plates and other pertinent information at gasoline stations; (2) transferring data from Field Observation Forms to computer data files; and (3) processing data from the state Department of Motor Vehicles (DMV) for comparison with EPA information on catalytic converter automobiles. A system of audits and cross checks was devised for both field and office procedures.

A. Field Observations: Accuracy in observing and recording license plate numbers in the field was audited in three ways: (1) dual observations; (2) dual audits; and (3) independent random audits.

(1) Dual observations were made by two observers at the same time and location. Observers agreed on the license number and fuel pumped prior to recording the information. If they could not agree, both license numbers were recorded. In this case, the description of the vehicle was particularly important as DMV records would indicate which number was correct by its description.

(2) Dual audits occurred when a field leader would assist in the usual dual observation but occasionally leave for a "rest break", but instead continue to record fueling operations without the partner's knowledge. A minimum of 6 vehicles were recorded using this procedure at each dual audit station.

The 6 audited license numbers were compared with the partner's original list and gave an indication of the reliability of that observer. Any conflicts were recorded as a "miss". This method of monitoring observer reliability was used on a minimum of 20% of gasoline stations included in the total study sample.

(3) Independent random audits were introduced to help maintain high accuracy standards when observers were working alone. Each morning, team members were assigned a list of stations to observe, as well as the probable route and observation sequence for the gasoline stations. This gave the field leader some idea where each team member might be at any given time. The leader would then adapt his/her own route to include one or more of the other observer's assigned stations without their knowledge. The team leader would make a 15 minute duplicate record while the other observation was in progress; preferably without the other observer's knowledge. This was then compared with the designated field form at the day's end. Conflicts were thrown out and recorded as a "miss". This audit procedure was done for a minimum of 6% of the total station observations.

By using these three methods, it was possible to determine the percent error, the type of error, and the relative accuracy of each observer. Observers with the highest reliability were assigned more time to work independently and accompany assistant observers as team leaders or dual auditors. (Audit results in Appendix C.)

B. Transfer of Data

All field data were audited in every phase of the transfer process as follows:

(1) Following the field activity, each Field Observation Form was checked for completeness and legibility and finally initialed by the observer responsible for completing that form. Each form was then rechecked and initialed by one or more other people to assure data was ready for entry into the computer data file.

(2) All of the data transcribed from the file forms to the computer file were audited at least twice. A printout of the original data entry was checked against the original forms and initialed by the individual who entered the data. The printout was again verified and initialed by one other person. This verification procedure was completed again if any additional errors were found. Where license numbers or fueling information was not complete resulting from some uncontrollable event in the field, a "miss" was recorded.

C. Motor Vehicle Registration Data

(1) A compatible computer tape containing vehicle license numbers was hand-carried to the respective state's Department of Motor Vehicles office (DMV) where the tape was run through their computers. The resulting DMV information required by the study was again hand-carried back to the EPA office. Procedure for the Boise portion

of the study was an exception to the procedure discussed above. An explanation of the unique measures required for Boise is discussed in succeeding sections.

(2) Information from the DMV tapes was entered into EPA's computer system. A printout was obtained that listed each vehicle observed by license number, make, model, vehicle identification number (VIN) and model year. This printout was then rechecked against the original Field Observation Form data for agreement. "Misses" were recorded when there was no DMV record of the license number observed or where the license number was protected by the DMV (Table 4).

(3) Once the make and model year of each vehicle surveyed was determined through the DMV, the fuel requirements could be assessed by referring to EPA reference materials and from the manufacturer through EPA Headquarters. The number of observed automobiles requiring unleaded gasoline in each city was then compared with the fuel actually seen being used and the fraction of switchers was then extrapolated.

AUDIT RESULTS

It was projected that an error rate of 2% or less would meet the criteria for field sample accuracy. Audit data indicated that field sample accuracy was held to less than 0.8% error overall. The greatest single error rate occurred in Eugene, where an independent audit revealed one error in 27 observations, or 3.7%, but this seems to have resulted by chance. Double observations and double audits for Eugene were one error (the same error) in 180 vehicle observations and one error (the same error) in 212 respectively, or 0.6% and 0.5%. Complete audit data may be found in Appendix C. The following table is a city-by-city quality assurance profile.

Table 2

Quality Assurance Audit Data

City-By-City

City	Double Observation Disagreements/Total	Double Audits/Total	Independent Audits/Total
Boise	0/90 = 0% error	0/207 = 0% error	0/30 = 0% error
Portland	1/190 = 0.52% error	1/434 = 0.2% error	0/59 = 0% error
Eugene	1/180 = 0.6% error	1/212 = 0.5% error	1/27 = 3.7% error
Seattle	4/987 = 0.4% error	3/1082 = 0.3% error	0/6 = 0% error
Spokane	4/647 = 0.6% error	6/751 = 0.8% error	1/99 = 1% error
Tacoma	5/355 = 1.4% error	11/677 = 1.6% error	0/15 = 0% error
TOTAL	15/2449 = 0.6% error	22/3363 = 0.65% error	2/236 = 0.8% error

MAJOR RESULTS

Technology Service Corporation of Santa Monica, California was responsible for the final evaluation of field data in this study. They were contracted to: (1) determine the percent of fuel switching and confidence intervals from field data taken in each of six Region X cities, (2) through collaboration with the field personnel, insure that field techniques satisfied survey design criteria that would be statistically defensible, and (3) indicate if and to what level of confidence statements might be made regarding causes for switching, such as price differential, gasoline trade name, type of vehicle, octane level, or city. Several of the tables used in this section were extracted from the Technology Service Corporation report. Their complete report appears in Appendix D.

A total of 432 stations were observed in the six cities. Table 3 describes the number of stations observed in each.

Table 3

Station Observations

City	No. of Stations Observed
Boise	87
Eugene	80
Portland	95
Seattle	61
Spokane	31
Tacoma	78
Total	432

Spokane and Seattle represent the smallest number of observations for two reasons: (1) Spokane was the first city studied, and various observation techniques and survey design criteria had to be negotiated with the contract consultants. Spokane therefore, represents the minimum acceptable representative sample. (2) Seattle is the largest urban area studied. The 1979 gasoline crisis caused extensive lines at the pumps and extremely high fueling volume at open stations. While only 61 stations were observed, each represents a larger average number of observed vehicles.

In Boise, a total 115 stations were observed, though only 87 were finally determined to be within the central commuting area. Boise's sample represents 100% of all gasoline retail outlets meeting study criteria. This was done to compensate for a unique problem encountered with the Idaho DMV, therefore, Boise is not a random but a complete station audit.

Idaho DMV does not have vehicle registration computerized; license numbers were retrieved from the DMV files manually by EPA field observation personnel. In Idaho, the license plate is registered to the owner and not to the vehicle. There were cases where a positive identification was made at the gasoline station, but it failed to match the vehicle described on the registration form. State DMV personnel said that this was a common problem when the owner failed to notify the DMV of the sale of the original vehicle or purchase of another. Where this occurred, the team member retrieving the information recorded a "miss" on the Field Observation Form, and it was not counted as an observed fueling. This variation from the computerized system of other states is not felt to have altered the validity of the information gathered.

Each license was double checked with the corresponding registration, and 100% rather than a random cross section of gasoline stations listed in the Boise Yellow Pages were observed.

There were approximately 9,000 vehicles observed in the survey of which 4,500 were determined to accept leaded gas, 3,000 required unleaded gas, and the fuel requirements of approximately 1,600 could not be identified. The following table lists the major causes for failing to identify fuel requirements.

Table 4

Unidentified Vehicles

Reason	No. of Vehicles Not Identified
1. No file in DMV	407
2. Unable to determine fuel requirements because of inadequate DMV records	556
3. Out of state license plate not checked	222
4. Could not see license plate (damaged, missing, blocked, etc.)	393
TOTAL	1,578

Of the 407 that were returned "No file", it was learned that some may have been unmarked police or classified vehicles whos identity was protected. The exact number of this description was undetermined.

There were 556 vehicles observed whos fuel requirements could not be classified. Many of these were utility, recreational, or special purpose vehicles that were ordered with custom engine modifications. This number represents those vehicles even the manufacturer could not classify after being given the vehicle identification number.

There were 222 unidentified out of state vehicles. Not all states were receptive to this study or charged enormous sums to run DMV record searches. A national police source was used but in many cases failed to offer adequate data on make, engine classification, model or model year to fulfill our requirements for determining fuel classification.

A survey average of 21 vehicles was observed fueling at each station. "The proportion of all service station visits by catalytic-converter-equipped vehicles in the urban area during the observation period that resulted in the purchase of leaded gasoline...", is defined as R* (TSC, 1979). Then R* can be estimated as a statistical mean with 95% confidence intervals from the observed service station visits. Table 5 is a city-by-city break out of those means and confidence intervals.

Table 5

City	R* Estimate (%)	95% Confidence Interval[1]
Boise	18.1	(13.7, 22.5)
Eugene	8.4	(5.2, 11.6)
Portland	6.0	(4.3, 7.7)
Seattle	7.0	(5.2, 10.6)
Spokane	7.3	(3.5, 11.1)
Tacoma	4.8	(2.3, 7.2)
		(TSC, 1979)

1. A 95% Confidence Interval indicates that there is a 95% chance that the true percentage of switchers falls between these two numbers. There is overlap in all the cities studied except Boise. Because of this overlap, it is possible that the true fuel switching rate is the same. Boise is the only city whos interval is beyond the range of any other city. Therefore, there is no significant statistical difference between any of the other Oregon or Washington cities studied, and Boise does represent a significantly higher rate of switching.

It was found throughout the survey that the majority of switching was for vans and pick-ups. Boise field data indicated a higher than average percentage of pick-ups in its total observed vehicle population. This may have influenced the elevated rate of switching found in this city, but further evidence is required to make any direct ties. The van population did not differ significantly from other cities monitored.

The R* for Portland and Eugene was 6.0 and 8.4 respectively. This suggests an apparent positive impact of Portland's I&M program, however, because there is overlap in their confidence intervals, it would require further documentation to be conclusive.

An overall estimate of fuel switching for Oregon and Washington's five urban areas was:

Estimated R* (%)	95% Confidence Interval (%)
6.9	(5.7, 8.1)

The format of the study did not allow sufficient data for conclusive analysis of the influences of price, octane, trade name, or self versus full service. In different states, the same trade name and classification of gasoline had different octane ratings. While Washington and Idaho offer self-service, Oregon has full service only. In some cities, the availability of gasoline was far more significant than price. Each parameter has a motivating affect on switching but in itself represents a unique and complex statistical problem. Trends may be suggested however, and appear in the contractors report. (Appendix D.)

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SAMPLE SURVEY DESIGN
REGION X, EPA

June 1979

Leo Breiman
Charles Stone

SURVEY DESIGN FOR ESTIMATING FUEL SWITCHING IN AN URBAN AREA

We deal with the problem of estimating the fraction of catalytic converter equipped vehicles that are using leaded gas. One approach is to conduct a survey of vehicles passing through service stations. Adopting this approach, suppose an urban area is selected and we propose to observe a number of service stations in the area in order to make our estimate. What we want to come up with is the fraction P of catalytic coverter cars passing through these stations that are buying leaded gas. This type of survey leads to the following questions:

1. What area-wide number is the survey attempting to estimate and is the fraction F observed as above a reasonable estimate of it?
2. How is the urban area defined?
3. How are the stations selected within the area?
4. How many cars should be observed at each station?
5. How will the catalytic converter cars be identified?
6. What are the sources of systematic error and how can these be reduced or compensated for?
7. What confidence statements (statistical error bounds) can be made regarding the accuracy of the estimate?

Following our discussions with the Region X personnel (William Schmidt and W. Douglas Smith) and after going over their draft design, we propose a some different design we discuss below, together with some answers to the above questions. The main alteration to the Region X design is a random mechanism for selecting the stations to be observed. Although this may seem like a minor change, it does permit the use of standard statistical

methodology to the computation of confidence intervals. We also propose two substudies for the purpose of estimating the size of systematic errors in the survey.

SAMPLE SURVEY DESIGN

The essential ideas of the sample survey are these:

1. Service stations are drawn at random from the yellow pages of the phone book (or books) covering the desired metropolitan area. Each of the stations is then assigned a random number. The number of stations drawn depends on the sample size requirements which, in turn, depend on the accuracy requirements. This will be discussed in more detail below.
2. The selected stations are then arranged by locale, i.e., are grouped together geographically. This is to reduce travel time between stations.
3. In each locale, the stations are visited in order of the assigned random numbers. If there are gas lines and the stations are only open a few hours each day, then at the beginning of the week all stations to be surveyed should be called and their open hours determined. If the visit plan by random number is not feasible because of the open hours - the order of visiting the stations should be rearranged to make a feasible schedule.
4. Each station should be observed for a fixed time period. We suggest two hours as a reasonable compromise time length. All cars passing through the station during that time should be observed.

In Appendix A we go through the selection of stations in the Seattle area using a random number table as applied to the yellow pages of the Seattle phone book. All the details will be illustrated there.

In Appendix B we do a preliminary computation of confidence intervals based on a reasonable statistical model. This computation gives us some ball park figures for sample size requriements for adequate estimates of switching in large urban area. We suggest a sample of 1000 catalytic converter cars with 40 stations being observed. If 4 stations a day are observed and an average of 100 cars per day surveyed, this gives 10 working day or two week survey per urban area (another possibility is a 1:10 survey).

Finally, we address the question of systematic error. In the Region X survey, the strategy is to note the license plate number of all vehicles which may be equipped with a catalytic converter. Because of a slow change in some models and makes, this may include some vehicles which are older than 1975, say, some 1972, 73 and 74 cars. These license number are then given to the automobile registration agency which produces make, model and year. If we assume that almost all cars without catalytic converters take leaded gas, then identification errors can bias our results upward. That is, suppose a 1974 car, because of a mistake either in recording the license number or in the registration data, is incorrectly identified as a catalytic converter car. Then, if it was observed taking leaded gas, it was incorrectly identified as a fuel switching car. In Appendix C we derive an estimate of the amount of upward bias B in the estimate due to a wrong identification of an older model car. The formula is

$$B = \tilde{Q}\tilde{P}n/N$$

where

Q = proportion of all registered cars that have catalytic converters

$\tilde{n}$ = number of recorded license plates registered to cars without catalytic converters

$\tilde{N}$ = number of recorded license plates registered to cars with catalytic converters

P = proportion of the sample with incorrectly recorded license numbers plus proportion of cars with registered license number not corresponding to the vehicle.

For instance, suppose $Q = .5$, $P = .1 + .1 = .2$ and $\tilde{n}/\tilde{N} = .3$,

then

$$B = .03$$

so that our estimate is 3% too high. The values Q, $\tilde{n}$, $\tilde{N}$ are easily found. However, the value of P poses more difficulty.

The registration error can be estimated by taking an unhurried sample of stationary vehicles, carefully noting year, make, model, color, license number, and checking against the registration output data for these vehicles.

The proportion of licenses incorrectly recorded is harder to get at. One possiblity is to compare independent observers over a test period. The difficulty is that performance over the test period can be significantly better than under normal operating conditions. This issue needs to be pursued with the Region X personnel.

APPENDIX A

RANDOM SELECTION OF SEATTLE SERVICE STATIONS

This section illustrates the use of a table of random number to select 40 service stations from the Seattle area. The population sampled consisted of all service stations listed in the yellow pages of the Seattle telephone book. A copy of these pages is in the back of this section. There were 742 listings. Many of these were double listings. For instance Al's Arco Station appeared both under its name and under Arco stations.

Also in back of this section are listed 10,000 random digits. One can start on any page. Our procedure was as follows: we used the random digits appearing on page 546. Look at the first column of 5 digits. The first number is 32847. Use the first three digits, 328, to locate the station. Looking at the telephone pages, the 328th listing is the home office of Gull Oil Co. Since this is not a service station, it is discarded. The next number in the column is 16916. The 169th listing is Rainier Chevron Service. But the station is double listed. To see whether to accept a double listed station, look at the 4th digit of the random number. If it is even, retain the station as a selection. If it is odd, do not accept. In the present case the 4th digit is odd, and Rainier Chevron is not selected.

In the telephone pages, the underlined stations are the ones corresponding to the first 3 digits in the column of random numbers. The E or O signify whether the 4th digit is even or odd. If even, the station is selected. If it is odd and <u>not</u> double-listed, it is selected, and if double-listed, not selected. The check by a station indicates that it was selected.

We sent down the 1st five-digit and 2nd five-figit columns until 40 stations were selected. The names, addresses and telephone numbers of these

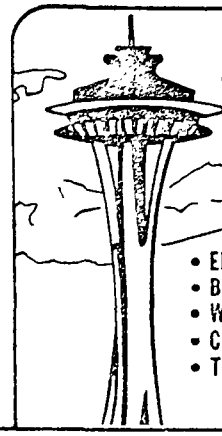
selected stations are listed in Table 1. The number following the station consists of the first two digits of the random number in the 3rd column. These numbers will be used to establish the order in which the stations will be visited.

TABLE 1 SERVICE STATIONS

Name	Address	Tel.	No.
Madison Park Arco	4000 E. Madison	324-7360	3
Dippy Duck Car Wash	16627 Bottell Way, NE		30
Bill's Arco	7810 SE 27th Mercer Isl.	232-9977	21
Bergie's Arco	523 15th E	324-2256	12
Bob's Exxon Service	18205 Des Moines Way S	244-6286	45
Mills Chevron Service Station	1554 NE 145th	362-9746	92
Rainier Self Serve	801 Rainier S	329-5398	91
Wedgewood Chevron	7300 35th NE	523-9470	98
Chevron Service Station	Brooklyn NE & NE 47th	525-9969	13
Dick's 76 Union	6956 Empire Wy S	725-8522	69
K & M Exxon Products Service	7833 SE 28th Mercer Isl	232-3007	52
Tree Exxon Service Station	4603 S 196th	433-9887	51
Exxon Self Service Station	16850 Pacific Hy S	242-5663	8
Gene's Mobil Service	4580 Fauntleroy Wy SW	938-0836	20
Genesee Automotive Sales & Service	3611 Genessee	723-6300	56
Glendale Arco Service	11215 8th S	243-3500	5
Greenwood Mobil Service Center	405th & Greenwood	783-7294	23
Gull Oil Co	3404 4th S	624-5900	7
Hegge Ted Chevron	7580-35th SW	938-3333	40
Howard's Exxon Products Service, Stn No 207	101 NE 50th	545-9666	27
Joe's Auto Service	6759 15th NW	782-8414	64
Ken's Shell Service	150001 Bothell Wy NE	362-9940	18

TABLE 1 SERVICE STATIONS (Cont'd)

Name	Address	Tel.	No.
Mac's Chevron Rainier	5 & Henderson	722-9390	84
Magnolia Union 76	3301 W McGraw	283-7600	79
Stubbs Highland Service	N 175th & Aurora Av N	545-3191	62
Benaroya Texaco	600 S Michigan	762-8012	29
Bob's Texaco	1935 N Northgate Wy	363-8817	93
Simpson Texaco	6230 Rainier S	723-1262	9
Angle Lake Union Service	2065 Pacific Hy S	873-3829	67
Broadway & Maidson Union Service	1100 Broadway	322-9694	38
Madison Street Union 76	1700 E. Madison	325-3356	85
North City Union	1211 NE 175th	362-9575	63
Queen Anne Union	218 W McGraw	236-9962	67
Spokane Street Union	3460 1st St	522-7600	39
Wayne's Shell Service	S 128th & Des Moines Wy S	433-9047	2
Werries 76 Service	7900 Greenwood N	782-9657	95
Pat & Tom's Texaco Service	2806 S 188th	433-9941	82
Rex's Phillip 66	Wilson & S Dawson	725-5944	7
Second & Union Parkade	1400 2d	624-1170	86
Tom's Shell Day & Night Towing	118 NE 45th	633-5400	25



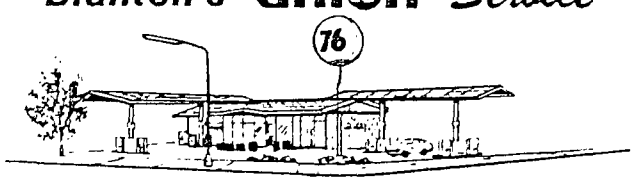
SEATTLE CENTER 76

- ELECTRONIC TUNE-UPS
- BRAKES - DISC & DRUMS
- WHEEL ALIGNMENT
- COMMERCIAL & FLEET ACCNTS WELCOME
- TIRES - SHOCKS - MUFFLERS

PICK-UP & DELIVERY

CLOSE TO SEATTLE CENTER
MOTELS - DOWNTOWN - FREEWAY
OPEN TODAY
623-2010
6th. & Denny Wy.

Blanton's UNION 76 Service



FULL SERVICE & SELF SERVICE
INCLUDING TUNE-UPS • AUTO AIR CONDITIONING
• TIRES • BRAKES
"WE BUY & SELL GOOD USED TIRES"

DOWNTOWN	NORTHGATE	LAKE CITY
107 FAIRVIEW N	11545 15th N E	8001 15th N E.
623-0087	363-2700	524-8152

SHELL

OPEN 7 DAYS
24 HOUR SERVICE
&
TOWING
MINOR REPAIRS
24 HOURS
MAJOR REPAIRS
7 A M 5 P M
AIR CONDITIONING SERVICE
WHEEL ALIGNMENT
NEW CAR WARRANTY
SHELL & AAA TIRES

GUS COOPER'S SHELL SERVICE
WOODLAND PARK ROOSEVELT DISTRICT
632-8812 & 525-8812
4605 FREMONT N 7501 ROOSEVELT WY. N.E
OPEN 24 HOURS

LAKE CITY

COMPLETE ENGINE WORK
FOREIGN & DOMESTIC

SHELL TIRES AND PRODUCTS
★ FRONT END ★ TUNE-UPS
★ BRAKES ★ ELECTRICAL
★ AIR CONDITIONING

TIM SCOTT'S LAKE CITY SHELL

524-0303
9017 LAKE CITY WAY NE

RAINIER DISTRICT

TEXACO

- GENERAL REPAIRS—BRAKE SERVICE
- ELECTRONIC TUNE-UPS—TIRES
- WHEEL BALANCING—STEAM CLEANING
- TOWING—ROAD SERVICE

OPEN 7 AM TO 10 PM 7 DAYS A WEEK

723-1262
6230 RAINIER S
SIMPSON TEXACO

Service Stations-Gasoline & Oil

Ace & Speed Service 10215 Greenwood N —784-2474
Admiral Shell 2347 California SW ——937-4500
Airport Arco 15001 Pacific Hy S ——246-3035
Airport Chevron 18514 Pacific Hy S ——246-5612

AIRPORT TEXACO
Brakes—Tune-Ups—3 Wy Alignment
Auto—Electrical—Service
Bank Cards Accepted
17010 Pacific Hy S ——433-9927

Alaska Native Petroleum Products
14211 Pacific Hy S ——242-5100

ALKI BURTON'S EXXON PRODUCTS
2504 Alki SW ——932-9845

AL'S ARCO 801 NE 65th ——524-6381
(Please See Advertisement This Page)

Anderson & Wedlund Texaco Service
15th NW & NW Market ——782-3550

Andy's Service Center 148 SW 160th ——243-9300

ARCO PETROLEUM PRODUCTS SERVICE STATIONS—

BALLARD

CHUCK'S BALLARD ARCO
5615 24th NW ——783-9900

CENTRAL

DERRY'S ARCO 523 15th E ——324-2256
HAROLD'S OLIVE WAY SERVICE
Pickup & Delivery-Tune Up-Minor Mechanical Repairs-Lubrications-Brakes-Undercoatings Emergency Service Capitol Hill & Downtown
Sundays 9 AM-4 PM
1611 E Olive Wy ——324-1268

EAST

MADISON PARK ARCO
4000 E Madison ——324-7360

MERCER ISLAND

DAN'S AUTOMOTIVE & ARCO SERVICE
7810 SE 27th MercerIsl ——232-6280

NORTH

ACE & SPEED SERVICE
10215 Greenwood N 784-2474
BOB'S ARCO MINI MART
14424 Greenwood N ——363-1700
BRESNAN'S NORTHGATE ARCO SERVICE
Electronic Scope Tune-Ups
Wheel Balancing-Brake Service & Alignment
2101 N Northgate Wy——364-0350
DON TAIE'S ARCO
General Repairs-Tune Ups & Brake Service
14507 Aurora N ——363-4464
FREMONT ARCO
3526 Fremont Pl N ——634-0574
HUSTON'S ARCO MINI MART
10504 Aurora N ——525-1234

NORTHEAST

AL'S ARCO 801 NE 65th——524-6381
BALLINGER WAY ARCO
18503 Ballinger Wy NE ——362-7290
BILL WATERS ARCO SERVICE
General Repairs-Tune-Ups & Brake Service
9500 35th NE——525-3387
CREST ARCO SERVICE
509 NE 165th——363-6247

Continued Next Page

COMPLETE CAR SERVICE

UNIVERSITY VILLAGE
Est. 1955

- MAJOR & MINOR CAR REPAIRS
- FOREIGN • DOMESTIC
- WARRANTY WORK • BRAKES
- TUNE-UPS • AIR CONDITIONING
- ROADSIDE SERVICE
- FREE PICK-UP & DELIVERY
ATLAS TIRES & BATTERIES

"WE NEVER SAY NO, IF WE CAN'T DO IT, WE KNOW WHO CAN"

UNIVERSITY VILLAGE

"ON TOP OF QFC" **525-0303** 4530 25TH NE

UNIVERSITY DISTRICT

AMERICAN & FOREIGN

- ELECTRONIC TUNE-UPS
- BRAKE SERVICE
- WHEEL ALIGNMENT

ARCO

• TIRES • BATTERIES • ACCESSORIES

AL'S ARCO

524-6381
801 N.E. 65TH

WEDGWOOD

FOREIGN & DOMESTIC

- Front End Work
- Valve Jobs
- Brake Service

- Diagnostic Tune-Ups
- Infra-Red Emission Diagnosis
- Electrical Repair • Exhaust Systems
- Road Service • Qualified Mechanic

522-8284

CHUCK'S

WEDGWOOD SHELL AUTO CARE
2501 N.E. 75th

Service Stations-Gasoline & Oil-(Cont'd)

ARCO PETROLEUM PRODUCTS SERVICE STATIONS—(Cont'd)

NORTHEAST-(Cont'd)

DON'S ARCO SERVICE
Repairs-Brakes-Goodyear Tires-Wheel Balancing-Tune-Ups
10822 Roosevelt Wy NE ---- 365-6226
GEOFFREY'S ARCO STATION
12354 15th NE ---- 364-8200
GREENLAKE AUTOMOTIVE
Electronic Tune-Up-Brake Service Starter & Generators-Wheel Balancing & Alignment-Goodyear Tires & Delco Batteries
7002 Woodlawn NE ---- 522-9108
HALLER LAKE ARCO
Complete Auto Repair
13401 Roosevelt Wy N ---- 363-2606
LEE'S NORTH CITY ARCO
Foreign & Domestic Auto Repair-Brake Service-Electronic Tune-Ups With Scope
1505 NE 175th ---- 364-9339
LITTLE AUTO SERVICE & SUPPLY
13435 15th NE ---- 362-9971
MARTY'S ARCO SERVICE
11577 Lake City Wy NE ---- 362-8787
RICK'S ARCO 8506 5th NE ---- 525-9392
RON'S SERVICE 3515 NE 45th ---- 524-1811
SAND POINT ARCO
Complete Car Service
9702 Sand Point Wy NE ---- 525-2726
TROTTER'S ARCO
Tune-Up & Repair
3418 NE 65th ---- 522-9758
UNIVERSITY MINI MARKET
4106 Brooklyn NE ---- 632-0908

NORTHWEST

EARL AND FRED'S ARCO SERVICE STATION
Tune-Ups & Brakes-Minor Repairs
7724 24th NW ---- 782-9774
ERIC'S GREENWOOD ARCO
Complete Automotive Repairs
7 AM-6 PM Daily-Closed Sunday
7410 Greenwood N ---- 783-6767
HARVEY'S AUTO SERVICE
9221 Holman Rd NW ---- 782-6686
JOE'S AUTO SERVICE
6759 15th NW ---- 782-8414
REARDON & JOHNSON AUTOMOTIVE
Hydramatic Specialists-Complete Major Overhaul
4420 Leary Wy NW ---- 783-0352
RICH'S ARCO 6501 32d NW ---- 789-3151

QUEEN ANNE

QUEEN ANNE ARCO
1929 Queen Anne N ---- 282-0462

SOUTH

BOB'S ARCO SERVICE 5304 1st S ---- 762-9871
BURIEN ARCO
Complete Car Maintenance-Specializing In Electrical Wiring-Hours-7 AM-11 PM
14653 1st S ---- 242-2660
GENESEE AUTOMOTIVE SALES & SERVICE 3611 S Genesee ---- 723-6300
GLENDALE ARCO SERVICE
11215 8th S ---- 243-3500
IMPERIAL RICHFIELD CO INC
Rainier S & Empire Wy S ---- 723-5890
JBM SERVICE
12025 Des Moines Wy S ---- 246-6352
KOHL & KOHL ARCO SERVICE
1046 1st S ---- 682-5230
MIKE'S ARCO SERVICE
6235 Airport Wy S ---- 763-0875
MOLNERS ONE STOP 8855 9th SW ---- 767-4918
RAINIER BEACH ARCO
9480 Rainier S ---- 725-8282
ROSE ST AUTO REPAIR
8335 Rainier S ---- 723-7500

SOUTHWEST

GARY'S WESTSIDE ARCO SERVICE
Complete Auto Maintenance & Supplies
3901 SW Alaska ---- 938-0800
MILLS TOM ARCO
Repair Of Volkswagen Vehicles
1505 SW Roxbury ---- 762-1662
ROY'S ARCO SERVICE
Complete Automotive Repair-Foreign & Domestic
7617 35th SW ---- 932-9975

Continued Next Column

ARCO PETROLEUM PRODUCTS SERVICE STATIONS—(Cont'd)

WEST

DON'S INTERBAY ARCO
Front End Alignment-Minor Repairs-Tune-Up-Brake Relining Pick-Up & Delivery
3201 20th W ---- 284-5427
RON'S ARCO 3 W Nickerson ---- 284-4010

ARNOLD'S TEXACO
Over 30 Years Experience
Complete Auto Repairs
Foreign-Domestic Big Or Small
2 Locations To Serve You
Uptown Texaco
631 Queen Anne N ---- 285-0200
Arnolds Texaco
Queen Anne & Denny Wy ---- 285-7810

Art's Highland Union Service
14056 Greenwood N ---- 365-3369
Astro Oil 1710 E Madison ---- 324-9916
Astro Oil Co 10645 16th SW ---- 242-3376
Aurora Exxon Self-Service Station
1504 Aurora N ---- 283-9960
Aurora Service Center 12815 Aurora N ---- 365-8540
Baldwin's Service 5450 Sand Point Wy NE ---- 523-9192
Ballard Chevron 2021 NW Market ---- 789-1219
Ballard Exxon Products Service
6500 15th NW ---- 783-7100
Ballard Union 5409 15th NW ---- 783-3103
Ballinger Way Arco
18503 Ballinger Wy NE ---- 362-7290
Barnecut Admiral Way Service
4100 SW Admiral Wy ---- 935-7588

BEACON AVE SHELL
Complete Automotive Air Conditioning
Tune-Ups—Brakes—Disc & Drum
All Makes—Bankcards Accepted
2424 Beacon S ---- 322-7861

Bell & Eaton Service 5100 25th NE ---- 525-0550
Benaroya Texaco 600 S Michigan ---- 762-8012
Bert's Gull Service 17704 15th NE ---- 367-0111
Bill Hall's Chevron Service 1424 NE 125th ---- 362-9923
Bill Waters Arco Service 9500 35th NE ---- 525-3387

BILL'S SHELL SERVICE
SHELL
AUTO CARE
N.I.A.S.E. CERTIFIED MECHANICS
15th & 145th NE
Engine & Electrical Repair
Brake Wheel Alignment
Tune-Ups Air Conditioning
All Makes
1513 NE 145th ---- 362-1223

BIRCHARD & AGEE SERVICE & MARINE 2424 NE 65th ---- 523-9400
Or ---- 522-0477
Blanton's Union 76 Service 8001 15th NE ---- 524-8152
BLANTON'S UNION 76 SERVICE
102 Fairview N ---- 623-0087
(Please See Advertisement Page 1280)
Bob's Arco Service 5304 1st S ---- 762-9871

BOB'S TEXACO
NORTHGATE
AREA
Authorized Warranty Work
TUNE-UPS—LUBRICATIONS
BRAKES—GOODYEAR TIRES
MINOR REPAIRS-AIR CONDITIONING
OPEN 7 DAYS
7 AM-10 PM Daily-Sun 10 AM-6 PM
1935 N Northgate Wy ---- 363-8817

Bob's Union
Crown Hill 8502 15th NW ---- 782-4030
Fremont 4600 Fremont N ---- 634-3165
Boren & Madison Chevron 1101 Madison ---- 623-0833

BOREN & STEWART CHEVRON
Electronic Tune-Ups—Brake Service
Front End Alignment
MINOR REPAIRS
1024 Stewart ---- 623-7990

BOTHELL WAY CHEVRON
6504 NE Bothell Wy Kenmore ---- 485-5500
Boulevard Park 76
11845 Des Moines Wy S ---- 248-0470
Bresnan's Northgate Arco Service
2101 N Northgate Wy ---- 364-0350

Continued Next Column

BROADVIEW TEXACO SERVICE
United Delco Tune-Up Service
DELCO SHOCKS
N 125th & Greenwood N ---- 362-2957

BROADWAY CHEVRON STATION
915 E Roy ---- 322-0195
Broadway Gull 1500 Broadway ---- 324-0919
Broadway & Madison Union Service
1100 Broadway ---- 324-3344
Broadway & Roy Union Service
700 Broadway E ---- 329-4635
Brown's Exxon Products 1426 34th ---- 323-9858
Burien Arco 14653 1st S ---- 242-2660
Burien Exxon Products 14807 1st S ---- 246-8093
Burien Gull 14302 1st S ---- 243-2486
Burien Texaco Service 14605 1st S ---- 433-9955
Campus Shell 700 12th ---- 324-4886
Carl's Shell Service 511 S Dearborn ---- 223-9155
CHAPMAN FRED CHEVRON
11750 Lake City Wy NE ---- 364-7180
Charley's Shell 15041 Des Moines Wy S ---- 242-1868

CHEVRON PRODUCTS
PEOPLE
REALLY
COUNT . . .
ALONG THE CHEVRON WAY
Chevron

DEALERS

AIRPORT-SEA-TAC

HARRY'S CHEVRON
Complete Auto Repairing-Tune-Ups-Standard Oil Products-Alignment-Brake Service
18514 Pacific Hy S ---- 246-5612
LARRY'S SEA-TAC CHEVRON SERVICE 15801 Pacific Hy S ---- 243-1366

ANGLE LAKE

ANGLE LAKE CHEVRON SERVICE
19923 Pacific Hy S Seattle ---- 878-7911

BALLARD

BALLARD CHEVRON
2021 NW Market ---- 789-1219

BELLEVUE

MAIN STREET CHEVRON
10812 Main Bellevue ---- 454-7468

BURIEN

CROMBIE FRED CHEVRON SERVICE
15804 Des Moines Wy S ---- 433-9969

CAPITOL HILL

BOREN & MADISON CHEVRON
Complete Automotive Service-Open 24 Hrs
1101 Madison ---- 623-0833
BROADWAY CHEVRON STATION
915 E Roy ---- 322-0195
RENTAS LOU CHEVRON STATION
General Repairs Road Side Service
1531 Broadway ---- 329-3331

DOWNTOWN

BOREN & MADISON CHEVRON
Complete Automotive Service-Open 24 Hrs
1101 Madison ---- 623-0833
BOREN & STEWART CHEVRON
1024 Stewart ---- 623-7990
Colman Building Garage
809 Western Av ---- 682-4991
GENE SNYDER'S CHEVRON
1024 Stewart ---- 623-7990
KNECHTEL CHEVRON SERVICE
2900 1st Av ---- 682-0737
MIKE BEASLEY'S CHEVRON SERVICE Denny Wy & Stewart ---- 623-5723
RED CARPET CAR WASH
1164 Denny Wy ---- 624-3317

DUWAMISH

DUWAMISH CHEVRON
Lubes-Brakes-Alignments-Atlas Tires-Batteries-Tune-Ups-Electronic Wheel Balance
South Of Boeing-E Marginal
10655 E Marginal Wy S ---- 762-7077

Continued Next Column

CHEVRON PRODUCTS—(Cont'd)

DEALERS-(Cont'd)

EASTLAKE

KELLY TERRY CHEVRON STATION
2727 Eastlake E ---- 329-1240

FEDERAL WAY

FEDERAL WAY TRUCK VILLAGE
S 348th & 16th S Federal Way
---- DES MOINES TEL NO 838-9014

FIRST HILL

BOREN & MADISON CHEVRON
Complete Automotive Service-Open 24 Hrs
1101 Madison ---- 623-0833
RAPHAEL FRED CHEVRON STATION
Foreign & Domestic Minor Repairs Front End Alignment-Tuneups Brakes Hallmark Award Station
914 James ---- 624-1108

GREENLAKE

GREENLAKE CHEVRON
Auto Repairing & Service Brakes & Tune-Up
6800 E Green Lake Wy N ---- 522-0488

GREENWOOD

RAY'S CHEVRON SERVICE
10415 Greenwood N ---- 782-9717
ROBBINS' CHEVRON SERVICE
Ryder Truck & Trailer Rentals
Propane Bottles Filled
14504 Greenwood N ---- 362-9715
TEX SALMON'S CHEVRON SERVICE CENTER
Tune-Ups-Front End Alignments
355 NW 85th ---- 789-1661

KENMORE

BOTHELL WAY CHEVRON
Tune-Ups Brakes Mufflers Minor Repairs
6504 NE Bothell Wy Kenmore ---- 485-5500
Kenmore Chevron
Bothell Hy & Juanita Dr Bothell ---- 486-6270

KIRKLAND

JUANITA CHEVRON SERVICE
11601 98th NE Kirkland ---- 823-6766

LAKE CITY

CHAPMAN FRED CHEVRON
11750 Lake City Wy NE ---- 364-7180

LAKE FOREST PARK

FOREST PARK CENTER CHEVRON SERVICE
Complete Lubrication-Brake & Tuneup
17017 Bothell Wy NE ---- 365-7565

MADISON PARK

Kelly Terry Chevron Station No 2
3115 E Madison ---- 325-2500

MAGNOLIA

KELLEY'S CHEVRON SERVICE
3848 34th W ---- 284-2330
MAGNOLIA VILLAGE CHEVRON
3300 W McGraw ---- 285-1761

MERCER ISLAND

CLYDE'S CHEVRON SERVICE
2800 Island Crest Wy MercerIsl ---- 232-9772
SOUTH MERCER CHEVRON
8407 SE 68th MercerIsl ---- 232-5555

MOUNT LAKE TERRACE

MIKE'S CHEVRON SERVICE
Towing-Tune-Up-Brakes-Steam Cleaning-Pickup & Delivery-Minor Repairs
20330 15th NE ---- 363-0066

NORMANDY PARK

Hickman Jim Chevron Service
Electronic Tune Ups-Brake Service
17651 1st S ---- 243-7484

NORTH CITY

TOM'S NORTH CITY CHEVRON
Tuneup-Brakes-Mufflers & Tail Pipes
17508 15th NE ---- 364-1840

Continued Next Page

Shopping is as simple as A-B-C if you use the Yellow Pages.

Need something? Get the habit of checking the Yellow Pages for where to buy.

Skiing this month? Don't forget to phone ahead for reservations.

Telephone service is a friendly service.

Service Stations-Gasoline & Oil-(Cont'd)

CHEVRON PRODUCTS—(Cont'd)

DEALERS-(Cont'd)

NORTH SEATTLE

BILL'S CHEVRON SERVICE
16425 Aurora N ---------- **542-2020**
MILLS' CHEVRON SERVICE STATION
Tune-Up-Brake Service Minor Repairs-Air Conditioning-Front End Alignment
1554 NE 145th ---------- **362-9746**

QUEEN ANNE

MERCER STREET CHEVRON
150 Mercer ---------- **285-9823**
QUEEN ANNE CHEVRON
Don Maxwell-Dealer
1417 Queen Anne N ---------- **284-1090**

RAINIER DISTRICT

RAINIER CHEVRON SERVICE
2800 Rainier S ---------- **723-3033**

RAINIER VALLEY

SMITH'S CHEVRON SERVICE
Towing Service Available
6061 Empire Wy S ---------- **725-3200**

RICHMOND BEACH

NELSON CHEVRON
Tune-Ups-Brakes-Air Conditioning-Minor Repairs-Tires-Batteries
1140 N 175th ---------- **546-2626**

RIVERTON HEIGHTS

RON'S CHEVRON
Tune Ups & Brake Service
Lubrication-Wheel Alignment
16260 Military Rd S ---------- **242-4222**

SANDPOINT

SANDPOINT CHEVRON
Repairs-Brakes-Tune Ups
Wheel Service-Pick Up & Delivery
5404 Sand Point Wy NE ---------- **524-2463**

SOUTH PARK

RUSS'S CHEVRON SERVICE
Repairs-Brakes-Tune-Ups
Electronic Wheel Balancing
Close To Boeings Main Plant
8700 14th S ---------- **762-3233**

SOUTH SEATTLE

Chevron Service Stations
5940 E Marginal Wy S ---------- 763-1567

SOUTHEND

MURRAY'S TRUCK TERMINAL
2244 6th S ---------- **682-0800**
RAY HALL'S CHEVRON 2740 1st S **223-9758**

TUKWILA

SOUTHCENTER CHEVRON
Tune-Ups & Wheel Alignments
220 Strander Bv ---------- **575-0360**

UNIVERSITY DISTRICT

Chevron Service Stations
Brooklyn NE & NE 47th ---------- 525-9969
MANLEY CHEVRON
Electronic Wheel Balancing
Lubrication-Tuneups-Brakes
4336 Roosevelt Wy NE ---------- **633-5534**
UNIVERSITY VILLAGE CHEVRON
Air Cond-Brakes-Rd Serv-Tune-Ups
4530 25th NE ---------- **525-0303**

WALLINGFORD

OIEN'S CHEVRON SERVICE
Minor Repairs-Tune-Ups-Brakes
1876 Bridge Wy N ---------- **632-2005**
WEBB LARRY CHEVRON SERVICE
New Car Warranty Service
Import & Domestic Repair-Service
1420 N 45th ---------- **633-1665**

WEDGEWOOD

LARRY ROE'S CHEVRON
[illegible] ---------- **525-2626**
WEDGEWOOD CHEVRON
Tune-Up-Brake Service-Pickup & Delivery
7300 35th NE ---------- **523-9470**

Continued Next Column

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CHEVRON PRODUCTS—(Cont'd)

DEALERS-(Cont'd)

WEST SEATTLE

DEAN MOON'S CHEVRON
Tune-Ups-Brakes-Atlas Tires & Batteries
2301 California SW ---------- **932-9822**
HEGGE TED CHEVRON
7580 35th SW ---------- **938-3333**
Stromberg's Chevron Station
3720 California SW ---------- 932-9835

WHITE CENTER

WHITE CENTER CHEVRON
1505 SW 98th ---------- **762-6226**

Chevron Service Stations
Brooklyn NE & NE 47th ---------- 525-9969
East Marginal Way S & 1st S
5940 E Marginal Wy S ---------- 763-1567
Chin Brothers Service 2901 17th S ---------- 324-4646

CHUCK'S EXXON PRODUCTS & SERVICE
Minor Repairs & Tune-Ups
Tires—Brakes—Mufflers—Shocks
Steam Cleaning—Pick-Up & Delivery
5620 Empire Wy S ---------- 722-0500

CHUCK'S WEDGWOOD SHELL AUTO CARE 2501 NE 75th ---------- **522-8284**
(Please See Advertisement Page 1280)
Cliff Houser's 76 11845 Des Moines Wy S ---------- 248-0470

CLYDE'S CHEVRON SERVICE
MERCER ISLAND
WRECKER SERVICE
DAY OR NIGHT
AIR-CONDITIONING
AAA EMERGENCY SERVICE
2800 Isl Crest Wy Mercer Isl ---------- 232-9772

Clyde's Chevron Service
2800 Island Crest Wy MercerIsl ---------- 232-9772
Coastal Oil Co Inc 13515 Ambaum Bv SW ---------- 242-9009
Collins' Service Station
10000 Empire Wy S ---------- 722-6696
Columbian Exxon Products
2050 S Columbian Wy ---------- 763-1366
Counter Balance Union Service
700 Queen Anne N ---------- 284-1076
Crest Arco Service 509 NE 165th ---------- 363-6247
Crombie Fred Chevron Service
15804 Des Moines Wy S ---------- 433-9969
Crossroads Shell 2921 Empire Wy S ---------- 723-9970
Dale's Texaco Service & Towing
210 NE 45th ---------- 632-1404

DAN'S VIEWRIDGE SHELL
VIEWRIDGE
Electronic Tune-Ups
Wheel Alignment
Specializing In
Brakes & Automatic Transmissions
Free Pick-Up & Delivery
Tires—Batteries—Road Service
7347 35th NE ---------- 525-5925

Dean Moon's Chevron 2301 California SW ---------- 932-9822
Dean's Texaco Svc 7301 15th NW ---------- 782-2111
Delridge-Way Exxon
7301 Delridge Wy SW ---------- 762-0448
Derry's Arco 523 15th E ---------- 324-2256
DICK'S 76 UNION 6956 Empire Wy S ---------- **723-8522**
Dick's Towing Inc 13038 Interurban S ---------- 243-1647
Discovery Park Automotive
3317 W Government Wy ---------- 282-0500
Don Taie's Arco 14507 Aurora N ---------- 363-4464
Don's Arco Service
10022 Roosevelt Wy NE ---------- 365-6226
Don's Interbay Arco 3201 20th W ---------- 284-5427
Don's Union 76 Service Station
2415 Beacon S ---------- 322-5722
Doug's Union 2501 NE 55th ---------- 524-5559

DUWAMISH CHEVRON
South Of Boeing On E. Marginal
Lubes—Brakes—Minor Repair
Alignment—Atlas Tires & Accessories
10655 E Marginal Wy S ---------- 762-7077

Earl And Fred's Arco Service Station
7724 24th NW ---------- 782-9774
Edwards Bros Service Center
5400 8th NW ---------- 789-1414
Egan & Sons Exxon 14438 Military Rd S ---------- 246-0441
EMPIRE TEXACO SERVICE
6600 Empire Wy S ---------- **722-9642**
Empire Way Gull 9834 Empire Wy S ---------- 722-7338
Empire Way Mobil 2801 Empire Wy S ---------- 722-4995

ERIC'S GREENWOOD ARCO
Complete Automotive Repairs
Open 7 AM-6 PM Daily — Closed Sunday
7418 Greenwood N ---------- 783-6767

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Ev's Mercer Avenue Shell
Mercer & Boren N ---------- 623-0954

EXXON PRODUCTS

EXXON Gasolines;
Uniflo Motor Oil,
A Complete Line of
Atlas ® Tires,
Batteries & Accessories

"WHERE TO GET SERVICE"

DISTRICT OFFICE

EXXON COMPANY U S A Bellevue ---------- **453-4500**

24 HOUR STATIONS & DEALERS

BALLARD EXXON PRODUCTS SERVICE
Tune-Ups-Brakes-Alignment General Repairs
6500 15th NW ---------- **783-7100**

SERVICE STATIONS & DEALERS

ALKI BURTON'S EXXON PRODUCTS
2504 Alki SW ---------- **932-9845**
BROWN'S EXXON PRODUCTS
Open 7-8 Every Day
1426 34th ---------- **323-9858**
BURIEN EXXON PRODUCTS
Complete Mechanical Service
14807 1st S ---------- **246-8093**
CHUCK'S EXXON PRODUCTS & SERVICE 5620 Empire Wy S ---------- **722-0500**
Egan & Sons Exxon
14438 Military Rd S ---------- 246-0441
EXXON SELF-SERVE STATION
8408 Aurora N ---------- **525-4788**
EXXON SELF SERVICE STATION
16850 Pacific Hy S ---------- **242-5668**
HIGHLINE EXXON
Corner Of Des Moines Way S & 8th S
Major & Minor Overhaul-Electronic Tune-Ups
18205 Des Moines Wy S ---------- **244-6286**
Holman Road Exxon Products Service
Tune-Ups-Brakes-Alignment
9701 Holman Rd NW ---------- 782-3030
HOWARD'S EXXON PRODUCTS SERVICE
Utility Trailers-For Rent
3400 California SW ---------- **937-6600**
Jerry's Exxon Service Center
2851 SW Roxbury ---------- 937-6155
John's Exxon Service
12911 Empire Wy S ---------- 772-6512
K & M Exxon Products Service
7833 SE 28th MercerIsl ---------- 232-3007
LEN & CLEV'S EXXON PRODUCTS & SERVICE 2841 S 188th ---------- **244-8610**
MURPHY JERRY EXXON PRODUCTS SERVICE STATION
Major Automobile Repairs And Service
7301 5th NE ---------- **522-0507**
PETZOLD'S EXXON SERVICE
2137 N Northgate Wy ---------- **362-9983**
REBEL JACKSON'S BURIEN EXXON PRODUCTS 14807 1st S ---------- **246-8093**
REBEL JACKSON'S VILLAGE EXXON
Complete Mechanical Service
17956 1st S ---------- **246-8053**
Riverton Heights Exxon Products
Office 14415 Pacific Hy S ---------- 244-1622
Products & Service
14415 Pacific Hy S ---------- 433-9958
SKYWAY EXXON PRODUCTS SERVICE
Complete Service-Free Pickup-Delivery
Brakes-Front End Alignment Tuneups
11655 Renton S ---------- **772-0660**
SMITH & McLAUCHLAN EXXON PRODUCTS 4004 NE 55th ---------- **522-8709**
SPENCER'S EXXON PRODUCTS SERVICE
Open 7.00 AM -6:00 PM Daily
SW 107th & 15th SW ---------- **244-2697**
STEVE'S EXXON SERVICE
Tune-Ups-Brakes-Lubrication-Emission Control
6056 Empire Wy S ---------- **723-1000**
TERMINAL SERVICE 2401 4th S ---------- **623-4675**
TERRACE EXXON SERVICE NO 2
20010 Ballinger Rd NE ---------- **364-8729**
Tyee Exxon Service Station
Specializing In Tires & Batteries & Lubrications
4603 S 188th ---------- 433-9887
VERDI'S EXXON SERVICE
16402 Military Rd S ---------- **244-7085**

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Exxon Self-Serv 420 NE 45th ---------- 632-9233
Exxon Self-Serve Station 8408 Aurora N ---------- 525-4788
Exxon Self Service Station
16850 Pacific Hy S ---------- 242-5668
Fast Gas
4001 California SW ---------- 932-9965
3810 S Morgan ---------- 723-2111
14711 15th NE ---------- 362-9779
Favors Service 932 19th ---------- 322-0680
Federal Way Truck Village
S 348th & 16th S Federal Way
---------- Des Moines Tel No 838-9014

FENNER'S TEXACO SERVICE
CROWN HILL
Minor Repairs—Tune-ups—Goodyear Tires
Pick-Up & Delivery
1701 NW 85th ---------- 783-6199

Fill-Em-Fast
4115 SW Admiral Wy ---------- 935-1082
14656 Ambaum Bv SW ---------- 246-7733
Flajole Bros Service 2201 4th S ---------- 345-9401
FOREST PARK CENTER CHEVRON SERVICE 17017 Bothell Wy NE ---------- **365-7565**
Forrest's Shell Service 6419 15th NW ---------- 784-8877
Fourth Ave Arco 2200 4th S ---------- 624-2697
4th Ave South Shell 6185 4th S ---------- 763-0505
Franklins Service 5406 California SW ---------- 935-4123
Frank's Self-Service 12603 Renton S ---------- 772-1380
Fremont Arco 3526 Fremont Pl N ---------- 634-0574
Freeway Garage 1512 8th ---------- 623-3806
Gary's Union Service 159 Denny Wy ---------- 622-6683
Gary's Westside Arco Service
3901 SW Alaska ---------- 938-0800
Gas Station The 21449 Pacific Hy S ---------- 824-5600
Gasco Inc 14805 Interurban S ---------- 241-0486
Gene Snyder's Chevron 1024 Stewart ---------- 623-7990
Gene's Mobil Service
4580 Fauntleroy Wy SW ---------- 938-0836
Geoffrey's Arco Station 12354 15th NE ---------- 364-8200
GEORGETOWN SHELL 6200 Corson S ---------- **767-6200**
Glendale Arco Service 11215 8th S ---------- 243-3500
Glendale Union 76 806 S 112th ---------- 243-5228
Glenn's R/C Automotive 2201 4th S ---------- 623-5584
Grant's Gas 'N' Go
1945 Aurora N ---------- 283-1693
13435 Interurban S ---------- 243-1103
7219 Rainier S ---------- 723-3169
2805 SW Roxbury ---------- 938-3656
6451 42d SW ---------- 932-9637
GREENLAKE AUTOMOTIVE
7002 Woodlawn NE ---------- **522-9108**
Greenlake Chevron
6800 E Green Lake Wy N ---------- 522-0488
Greenlake Gas & Auto Repair
6501 Aurora N ---------- 782-6094
Grinhagen's Wally Shell Service
11346 Lake City Wy NE ---------- 362-2236
Grosvenor House Garage 505 Vine ---------- 623-0033
Gull Industries 2005 E Madison ---------- 329-3700

GULL SERVICE STATIONS

QUALITY
GASOLINE
FOR LESS

"WHERE TO BUY IT"

HOME OFFICE

GULL INDUSTRIES INC 3404 4th S **624-5900**

BROADWAY

Broadway Gull 1500 Broadway ---------- 324-0919

ROOSEVELT

Roosevelt Gull 6417 Roosevelt Wy NE ---------- 524-4199

SOUTH INDUSTRIAL AREA

Pingrey's Gull 4115 4th S ---------- 623-5320

WHITE CENTER

White Center Gull 11007 16th SW ---------- 248-1570

Gull Station Georgetown
Corson S & S Michigan ---------- 763-8676
GUS COOPER'S ROOSEVELT SHELL
7501 Roosevelt Wy NE ---------- **525-8812**
GUS COOPER'S SHELL SERVICE
4605 Fremont N ---------- **632-8812**
(Please See Advertisement Page 1280)
Hadfield's Garage 3127 E Madison ---------- 322-4965
HAL'S SHELL SERVICE
Expert Brake Service & Tune-Up
2244 Eastlake E ---------- **323-9438**
HANCOCK—
U-SAVE OIL CO
9076 Holman Rd NW ---------- 782-4930

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TABLE A 1
TEN THOUSAND RANDOMLY ASSORTED DIGITS

	00–04	05–09	10–14	15–19	20–24	25–29	30–34	35–39	40–44	45–49
00	54463	22662	65905	70639	79365	67382	29085	69831	47058	08186
01	15389	85205	18850	39226	42249	90669	96325	23248	60933	26927
02	85941	40756	82414	02015	13858	78030	16269	65978	01385	15345
03	61149	69440	11286	88218	58925	03638	52862	62733	33451	77455
04	05219	81619	10651	67079	92511	59888	84502	72095	83463	75577
05	41417	98326	87719	92294	46614	50948	64886	20002	97365	30976
06	28357	94070	20652	35774	16249	75019	21145	05217	47286	76305
07	17783	00015	10806	83091	91530	36466	39981	62481	49177	75779
08	40950	84820	29881	85966	62800	70326	84740	62660	77379	90279
09	82995	64157	66164	41180	10089	41757	78258	96488	88629	37231
10	96754	17676	55659	44105	47361	34833	86679	23930	53249	27083
11	34357	88040	53364	71726	45690	66334	60332	22554	90600	71113
12	06318	37403	49927	57715	50423	67372	63116	48888	21505	80182
13	62111	52820	07243	79931	89292	84767	85693	73947	22278	11551
14	47534	09243	67879	00544	23410	12740	02540	54440	32949	13491
15	98614	75993	84460	62846	59844	14922	48730	73443	48167	34770
16	24856	03648	44898	09351	98795	18644	39765	71058	90368	44104
17	96887	12479	80621	66223	86085	78285	02432	53342	42846	94771
18	90801	21472	42815	77408	37390	76766	52615	32141	30268	18106
19	55165	77312	83666	36028	28420	70219	81369	41943	47366	41067
20	75884	12952	84318	95108	72305	64620	91318	89872	45375	85436
21	16777	37116	58550	42958	21460	43910	01175	87894	81378	10620
22	46230	43877	80207	88877	89380	32992	91380	03164	98656	59337
23	42902	66892	46134	01432	94710	23474	20423	60137	60609	13119
24	81007	00333	39693	28039	10154	95425	39220	19774	31782	49037
25	68089	01122	51111	72373	06902	74373	96199	97017	41273	21546
26	20411	67081	89950	16944	93054	87687	96693	87236	77054	33848
27	58212	13160	06468	15718	82627	76999	05999	58680	96739	63700
28	70577	42866	24969	61210	76046	67699	42054	12696	93758	03283
29	94522	74358	71659	62038	79643	79169	44741	05437	39038	13163
30	42626	86819	85651	88678	17401	03252	99547	32404	17918	62880
31	16051	33763	57194	16752	54450	19031	58580	47629	54132	60631
32	08244	27647	33851	44705	94211	46716	11738	55784	95374	72655
33	59497	04392	09419	89964	51211	04894	72882	17805	21896	83864
34	97155	13428	40293	09985	58434	01412	69124	82171	59058	82859
35	98409	66162	95763	47420	20792	61527	20441	39435	11859	41567
36	45476	84882	65109	96597	25930	66790	65706	61203	53634	22557
37	89300	69700	50741	30329	11658	23166	05400	66669	48708	03887
38	50051	95137	91631	66315	91428	12275	24816	68091	71710	33258
39	31753	85178	31310	89642	98364	02306	24617	09609	83942	22716
40	79152	53829	77250	20190	56535	18760	69942	77448	33278	48805
41	44560	38750	83635	56540	64900	42912	13953	79149	18710	68618
42	68328	83378	63369	71381	39564	05615	42451	64559	97501	65747
43	46939	38689	58625	08342	30459	85863	20781	09284	26333	91777
44	83544	86141	15707	96256	23068	13782	08467	89469	93842	55349
45	91621	00881	04900	54224	46177	55309	17852	27491	89415	23466
46	91896	67126	04151	03795	59077	11848	12630	98375	52068	60142
47	55751	62515	21108	80830	02263	29303	37204	96926	30506	09808
48	85156	87689	95493	88842	00664	55017	55539	17771	69448	87530
49	07521	56898	12236	60277	39102	62315	12239	07105	11844	01117

TABLE A 1—(*Continued*)

	50–54	55–59	60–64	65–69	70–74	75–79	80–84	85–89	90–94	95–99
00	59391	58030	52098	82718	87024	82848	04190	96574	90464	29065
01	99567	76364	77204	04615	27062	96621	43918	01896	83991	51141
02	10363	97518	51400	25670	98342	61891	27101	37855	06235	33316
03	86859	19558	64432	16706	99612	59798	32803	67708	15297	28612
04	11258	24591	36863	55368	31721	94335	34936	02566	80972	08188
05	95068	88628	35911	14530	33020	80428	39936	31855	34334	64865
06	54463	47237	73800	91017	36239	71824	83671	39892	60518	37092
07	16874	62677	57412	13215	31389	62233	80827	73917	82802	84420
08	92494	63157	76593	91316	03505	72389	96363	52887	01087	66091
09	15669	56689	35682	40844	53256	81872	35213	09840	34471	74441
10	99116	75486	84989	23476	52967	67104	39495	39100	17217	74073
11	15696	10703	65178	90637	63110	17622	53988	71087	84148	11670
12	97720	15369	51269	69620	03388	13699	33423	67453	43269	56720
13	11666	13841	71681	98000	35979	39719	81899	07449	47985	46967
14	71628	73130	78783	75691	41632	09847	61547	18707	85489	69944
15	40501	51089	99943	91843	41995	88931	73631	69361	05375	15417
16	22518	55576	98215	82068	10798	86211	36584	67466	69373	40054
17	75112	30485	62173	02132	14878	92879	22281	16783	86352	00077
18	80327	02671	98191	84342	90813	49268	95441	15496	20168	09271
19	60251	45548	02146	05597	48228	81366	34598	72856	66762	17002
20	57430	82270	10421	00540	43648	75888	66049	21511	47676	33444
21	73528	39559	34434	88596	54086	71693	43132	14414	79949	85193
22	25991	65959	70769	64721	86413	33475	42740	06175	82758	66248
23	78388	16638	09134	59980	63806	48472	39318	35434	24057	74739
24	12477	09965	96657	57994	59439	76330	24596	77515	09577	91871
25	83266	32883	42451	15579	38155	29793	40914	65990	16255	17777
26	76970	80876	10237	39515	79152	74798	39357	09054	73579	92359
27	37074	65198	44785	68624	98336	84481	97610	78735	46703	98265
28	83712	06514	30101	78295	54656	85417	43189	60048	72781	72606
29	20287	56862	69727	94443	64936	08366	27227	05158	50326	59566
30	74261	32592	86538	27041	65172	85532	07571	80609	39285	65340
31	64081	49863	08478	96001	18888	14810	70545	89755	59064	07210
32	05617	75818	47750	67814	29575	10526	66192	44464	27058	40467
33	26793	74951	95466	74307	13330	42664	85515	20632	05497	33625
34	65988	72850	48737	54719	52056	01596	03845	35067	03134	70322
35	27366	42271	44300	73399	21105	03280	73457	43093	05192	48657
36	56760	10909	98147	34736	33863	95256	12731	66598	50771	83665
37	72880	43338	93643	58904	59543	23943	11231	83268	65938	81581
38	77888	38100	03062	58103	47961	83841	25878	23746	55903	44115
39	28440	07819	21580	51459	47971	29882	13990	29226	23608	15873
40	63525	94441	77033	12147	51054	49955	58312	76923	96071	05813
41	47606	93410	16359	89033	89696	47231	64498	31776	05383	39902
42	52669	45030	96279	14709	52372	87832	02735	50803	72744	88208
43	16738	60159	07425	62369	07515	82721	37875	71153	21315	00132
44	59348	11695	45751	15865	74739	05572	32688	20271	65128	14551
45	12900	71775	29845	60774	94924	21810	38636	33717	67598	82521
46	75086	23537	49939	33595	13484	97588	28617	17979	70749	35234
47	99495	51434	29181	09993	38190	42553	68922	52125	91077	40197
48	26075	31671	45386	36583	93459	48599	52022	41330	60651	91321
49	13636	93596	23377	51133	95126	61496	42474	45141	46660	42338

TABLE A 1—(*Continued*)

	00–04	05–09	10–14	15–19	20–24	25–29	30–34	35–39	40–44	45–49
50	64249	63664	39652	40646	97306	31741	07294	84149	46797	82487
51	26538	44249	04050	48174	65570	44072	40192	51153	11397	58212
52	05845	00512	78630	55328	18116	69296	91705	86224	29503	57071
53	74897	68373	67359	51014	33510	83048	17056	72506	82949	54600
54	20872	54570	35017	88132	25730	22626	86723	91691	13191	77212
55	31432	96156	89177	75541	81355	24480	77243	76690	42507	84362
56	66890	61505	01240	00660	05873	13568	76082	79172	57913	93448
57	41894	57790	79970	33106	86904	48119	52503	24130	72824	21627
58	11303	87118	81471	52936	08555	28420	49416	44448	04269	27029
59	54374	57325	16947	45356	78371	10563	97191	53798	12693	27928
60	64852	34421	61046	90849	13966	39810	42699	21753	76192	10508
61	16309	20384	09491	91588	97720	89846	30376	76970	23063	35894
62	42587	37065	24526	72602	57589	98131	37292	05967	26002	51945
63	40177	98590	97161	41682	84533	67588	62036	49967	01990	72308
64	82309	76128	93965	26743	24141	04838	40254	26065	07938	76236
65	79788	68243	59732	04257	27084	14743	17520	95401	55811	76099
66	40538	79000	89559	25026	42274	23489	34502	75508	06059	86682
67	64016	73598	18609	73150	62463	33102	45205	87440	96767	67042
68	49767	12691	17903	93871	99721	79109	09425	26904	07419	76013
69	76974	55108	29795	08404	82684	00497	51126	79935	57450	55671
70	23854	08480	85983	96025	50117	64610	99425	62291	86943	21541
71	68973	70551	25098	78033	98573	79848	31778	29555	61446	23037
72	36444	93600	65350	14971	25325	00427	52073	64280	18847	24768
73	03003	87800	07391	11594	21196	00781	32550	57158	58887	73041
74	17540	26188	36647	78386	04558	61463	57842	90382	77019	24210
75	38916	55809	47982	41968	69760	79422	80154	91486	19180	15100
76	64288	19843	69122	42502	48508	28820	59933	72998	99942	10515
77	86809	51564	38040	39418	49915	19000	58050	16899	79952	57849
78	99800	99566	14742	05028	30033	94889	53381	23656	75787	59223
79	92345	31890	95712	08279	91794	94068	49337	88674	35355	12267
80	90363	65162	32245	82279	79256	80834	06088	99462	56705	06118
81	64437	32242	48431	04835	39070	59702	31508	60935	22390	52246
82	91714	53662	28373	34333	55791	74758	51144	18827	10704	76803
83	20902	17646	31391	31459	33315	03444	55743	74701	58851	27427
84	12217	86007	70371	52281	14510	76094	96579	54853	78339	20839
85	45177	02863	42307	53571	22532	74921	17735	42201	80540	54721
86	28325	90814	08804	52746	47913	54577	47525	77705	95330	21866
87	29019	28776	56116	54791	64604	08815	46049	71186	34650	14994
88	84979	81353	56219	67062	26146	82567	33122	14124	46240	92973
89	50371	26347	48513	63915	11158	25563	91915	18431	92978	11591
90	53422	06825	69711	67950	64716	18003	49581	45378	99878	61130
91	67453	35651	89316	41620	32048	70225	47597	33137	31443	51445
92	07294	85353	74819	23445	68237	07202	99515	62282	53809	26685
93	79544	00302	45338	16015	66613	88968	14595	63836	77716	79596
94	64144	85442	82060	46471	24162	39500	87351	36637	42833	71875
95	90919	11883	58318	00042	52402	28210	34075	33272	00840	73268
96	06670	57353	86275	92276	77591	46924	60839	55437	03183	13191
97	36634	93976	52062	83678	41256	60948	18685	48992	19462	96062
98	75101	72891	85745	67106	26010	62107	60885	37503	55461	71213
99	05112	71222	72654	51583	05228	62056	57390	42746	39272	96659

TABLE A 1—(*Continued*)

	50–54	55–59	60–64	65–69	70–74	75–79	80–84	85–89	90–94	95–99
50	32847	31282	03345	89593	69214	70381	78285	20054	91018	16742
51	16916	00041	30236	55023	14253	76582	12092	86533	92426	37655
52	66176	34037	21005	27137	03193	48970	64625	22394	39622	79085
53	46299	13335	12180	16861	38043	59292	62675	63631	37020	78195
54	22847	47839	45385	23289	47526	54098	45683	55849	51575	64689
55	41851	54160	92320	69936	34803	92479	33399	71160	64777	83378
56	28444	59497	91586	95917	68553	28639	06455	34174	11130	91994
57	47520	62378	98855	83174	13088	16561	68559	26679	06238	51254
58	34978	63271	13142	82681	05271	08822	06490	44984	49307	61717
59	37404	80416	69035	92980	49486	74378	75610	74976	70056	15478
60	32400	65482	52099	53676	74648	94148	65095	69597	52771	71551
61	89262	86332	51718	70663	11623	29834	79820	73002	84886	03591
62	86866	09127	98021	03871	27789	58444	44832	36505	40672	30180
63	90814	14833	08759	74645	05046	94056	99094	65091	32663	73040
64	19192	82756	20553	58446	55376	88914	75096	26119	83898	43816
65	77585	52593	56612	95766	10019	29531	73064	20953	53523	58136
66	23757	16364	05096	03192	62386	45389	85332	18877	55710	96459
67	45989	96257	23850	26216	23309	21526	07425	50254	19455	29315
68	92970	94243	07316	41467	64837	52406	25225	51553	31220	14032
69	74346	59596	40088	98176	17896	86900	20249	77753	19099	48885
70	87646	41309	27636	45153	29988	94770	07255	70908	05340	99751
71	50099	71038	45146	06146	55211	99429	43169	66259	97786	59130
72	10127	46900	64984	75348	04115	33624	68774	60013	35515	62556
73	67995	81977	18984	64091	02785	27762	42529	97144	80407	64524
74	26304	80217	84934	82657	69291	35397	98714	35104	08187	48109
75	81994	41070	56642	64091	31229	02595	13513	45148	78722	30144
76	59537	34662	79631	89403	65212	09975	06118	86197	58208	16162
77	51228	10937	62396	81460	47331	91403	95007	06047	16846	64809
78	31089	37995	29577	07828	42272	54016	21950	86192	99046	84864
79	38207	97938	93459	75174	79460	55436	57206	87644	21296	43393
80	88666	31142	09474	89712	63153	62333	42212	06140	42594	43671
81	53365	56134	67582	92557	89520	33452	05134	70628	27612	33738
82	89807	74530	38004	90102	11693	90257	05500	79920	62700	43325
83	18682	81038	85662	90915	91631	22223	91588	80774	07716	12548
84	63571	32579	63942	25371	09234	94592	98475	76884	37635	33608
85	68927	56492	67799	95398	77642	54913	91583	08421	81450	76229
86	56401	63186	39389	88798	31356	89235	97036	32341	33292	73757
87	24333	95603	02359	72942	46287	95382	08452	62862	97869	71775
88	17025	84202	95199	62272	06366	16175	97577	99304	41587	03686
89	02804	08253	52133	20224	68034	50865	57868	22343	55111	03607
90	08298	03879	20995	19850	73090	13191	18963	82244	78479	99121
91	59883	01785	82403	96062	03785	03488	12970	64896	38336	30030
92	46982	06682	62864	91837	74021	89094	39952	64158	79614	78235
93	31121	47266	07661	02051	67599	24471	69843	83696	71402	76287
94	97867	56641	63416	17577	30161	87320	37752	73276	48969	41915
95	57364	86746	08415	14621	49430	22311	15836	72492	49372	44103
96	09559	26263	69511	28064	75999	44540	13337	10918	79846	54809
97	53873	55571	00608	42661	91332	63956	74087	59008	47493	99581
98	35531	19162	86406	05299	77511	24311	57257	22826	77555	05941
99	28229	88629	25695	94932	30721	16197	78742	34974	97528	45447

Appendix B

COMPUTATION OF CONFIDENCE INTERVALS

Model:

Assumptions: j^{th} driver has probability q_j of gassing up on any day. Given that he gasses up, he gets gas at station s with probability $p_j(s)$ where s denotes the station I.D.

Assume that

$$\sum_s p_j(s) = 1$$

That is, we have included in our model all stations that have a non-zero probability of use by a driver in our population.

Let

$$H(j) = \begin{cases} 1, & j^{th} \text{ driver is switcher} \\ 0, & \text{otherwise} \end{cases}$$

Let J = total number drivers driving catalytic converter cars.

The proportion of switchers is

$$P = \frac{1}{J}\sum_j H(j)$$

Observe stations $s_1, s_2, \ldots, s_k$ selected at random. At station s_i observe total of n_i catalytic converter cars, and m_i switchers. At each station the duration of observation is the same. Consider the ratio

$$R = \frac{\sum_{i=1}^{k} m_i}{\sum_{i=1}^{k} n_i}$$

The question is: what is R an estimate of: To answer this, define

$$q(SW) = \text{av. } q_j \quad \text{for switchers}$$
$$q(NS) = \text{av. } q_j \quad \text{for non-switchers}$$

We allow the possibility that

$$q(SW) \neq q(NS).$$

That is, the average probability that a switcher gets gas on a given day may be different than the average probability for a non-switcher. Intuitively, one may suspect that a switcher may be a larger gas consumer and be likely to make more frequent visits to gas up. We will show that R is an asymptotically unbiased estimate of

$$R^* = \frac{P\, q(SW)}{Pq(SW) + (1-P)q(NS)}$$

Thus, we get, not an estimate of P, but an estimate of P weighted by (approximately) q(SW)/q(NS). That is, if we assume P is small, then

$$R^* \simeq P\, \frac{q(SW)}{q(NS)}$$

If we assume q(SW) = q(NS) then R* = P.

The fact that R* gives a weighted estimate of P is not surprising. If switchers turn up more frequently at service stations than non-switchers, they will be observed more often.

To derive the above result and also to derive the distribution of the estimate R, we assume that the stations are sampled with replacement. This is a good approximation if the number of stations surveyed is small compared to the total number of stations. Let S be the total number of stations, let n_s, m_s be the random variables defined as the total number of catalytic converter cars and switchers we would observe if station s were observed at a fixed duration period (i.e., two hours) randomly selected during the day on a randomly selected day. Let N_s, M_s be the numbers of catalytic converter cars and switchers we would observe at stations s if observed over the full duration of randomly selected day. Assume that

$$En_s = \alpha\, EN_s$$
$$Em_s = \alpha\, EM_s$$

where E denotes expectation.

Now, note that

$$EN_s = \sum_j p_j(s)\, q_j$$
$$EM_s = \sum_j p_j(s)\, q_j\, H(j)$$

Let s* be a random selection from the set {1, 2, ...,S} of all service stations.

Then

$$EN_{s*} = \frac{1}{S} \sum_{s=1}^{S} EN_s$$

$$EM_{s*} = \frac{1}{S} \sum_{s=1}^{S} EM_s$$

so

$$EN_{s*} = \frac{1}{S} \sum_{s} \sum_{j} p_j(s)\ q_j$$

$$= \frac{1}{S} \sum_{j} q_j$$

$$= \frac{J}{S} [Pq(SW) + (1-P)\ q(NS)]$$

and

$$EM_{s*} = \frac{1}{S} \sum_{s} \sum_{j} p_j(s)\ q_j\ H(j)$$

$$= \frac{PJ}{S} q(SW)$$

Therefore,

$$E(\sum_{i=1}^{k} n_i) = \frac{K\alpha J}{S} [Pq(SW) + (1-P)\ q(NS)$$

$$E(\sum_{i=1}^{k} m_i) = \frac{K\alpha PJ}{S}\ q(SW)$$

So

$$\frac{E(\sum_{i=1}^{k} m_i)}{E(\sum_{i=1}^{k} n_i)} = R^*$$

The next thing we want to derive is the value of

$$L = E(R-R^*)^2$$

or, at least, an upper bound for L. Denote

$$X = \sum_{i=1}^{k} m_i$$

$$Y = \sum_{i=1}^{k} n_i$$

Then

$$L^2 = E\left(\frac{X}{Y} - \frac{EX}{EY}\right)^2$$

$$= E\left(\frac{X(EY) - Y(EX)}{Y(EY)}\right)^2$$

Denote $\tilde{X} = X - EX, \quad \tilde{Y} = Y - EY$

Then

$$L^2 = E\left(\frac{\tilde{X}(EY) - \tilde{Y}(EX)}{YEY}\right)^2$$

Use the inequality

$$E(U + V)^2 \leq \left(\sqrt{EV^2} + \sqrt{EV^2}\right)^2$$

to get

$$L^2 \leq \sqrt{E(\tilde{X}/Y)^2} + \left(\frac{EX}{EY}\right) \cdot \sqrt{E(\tilde{Y}/Y)^2}^{\,2}$$

Since Y is a sum of K identically distributed independent random variables, to a first order, we assume

$$Y \sim EY$$

to get

$$L^2 \leq \left(\frac{\sqrt{V(X)}}{EY} + \frac{(EX)\sqrt{V(Y)}}{(EY)^2}\right)^2$$

where V denote variance.

Now

$$EX = kEm_{s*} \ , \quad EY = kEn_{s*}$$

$$V(X) = kV(m_{s*}) \quad V(Y) = kV(n_{s*})$$

Thus

$$L \leq \frac{1}{\sqrt{k}} \left[\frac{\sigma(m_{s*})}{Em_{s*}} + \frac{(Em_{s*})\ \sigma(n_{s*})}{(Em_{s*})^2}\right] =$$

$$\frac{1}{\sqrt{k}} \cdot \frac{Em_{s*}}{En_{s*}} \left[\frac{\sigma(m_{s*})}{Em_{s*}} + \frac{\sigma(n_{s*})}{En_{s*}}\right] =$$

$$\frac{1}{\sqrt{k}}\ R^* \left[\frac{\sigma(m_{s*})}{Em_{s*}} + \frac{\sigma(n_{s*})}{En_{s*}}\right]$$

Once the survey is finished, the values in this bound for L may be replaced by sample estimates, i.e., R* may be replaced by R, the standard deviations $\sigma(m_{s*})$ and $\sigma(n_{s*})$ may be replaced by the sample standard deviations, etc.

To get a rough a priori estimate of the accuracy of the survey, we assume that all n_i, m_i are Poisson variables with means μ, λ not depending on i and $\lambda = \mu P$. Then we get, assuming P small, say $P \leq .3$,

$$L \leq \frac{R^*}{\sqrt{k\lambda}} = \frac{R^*}{\sqrt{k\mu P}}$$

and assuming, $R^* \simeq P$, we get

$$L \leq \sqrt{\frac{P}{n}}$$

where n is the number of catalytic converter cars observed. This bound is low because of the assumption of the equality of the λ_i. Take the bound to be $2\sqrt{\frac{P}{n}}$ even though this is probably too high. To get some idea of sample size requirements, suppose P = .25, then the bound is $1/\sqrt{n}$. If we want the 95% confidence interval to be

$$.25 \pm .05$$

then $2/\sqrt{n} \simeq .05$ or

$$n = 1600$$

This is probably too large a sample size to go for and our opinion is that a sample size of 1000 cars is sufficient. If 100 catalytic converter cars are observed per day at 4 different stations - this gives a 10 day survey survey covering 40 stations. This seems reasonable and feasible.

Appendix C

BIAS COMPUTATION

Define

P_L = probability of incorrect registration identification

P_0 = probability of incorrect license number recording

$P = P_0 + P_L$

Q = proportion of all vehicles that have catalytic converters

To compute: given a non-catalytic converter car, what is the probability P_{cc} that it is identified as a catalytic converter car?

Two possiblities: registration wrong
recording wrong

Even if a non-catalytic car is incorrectly identified for either of the two above reasons, it can still be identified as a non-catalytic converter car. Thus, we will assume that if a non-catalytic converter car is incrorectly identified, the probability that it is identified as a catalytic converter car is equal to the proportion Q of catalytic converter cars. in the entire population. Therefore

$$P_{cc} = Q \Pr(\text{incorrect identification}).$$

Now, assuming independence,

$$\Pr(\text{correct identification}) = (1 - P_L)(1 - P_0)$$

so

$$\begin{aligned}\Pr(\text{incorrect identification}) &= 1 - (1 - P_L)(1 - P_0) \\ &= P_L + P_0 - P_L P_0 \cdot \\ &\simeq P_L + P_0\end{aligned}$$

The bias B is the proportion of cars identified as catalytic converter cars that are actually non-catalytic converter. Denote

n = true number of non-catalytic cars observed

N = true number catalytic cars observed.

Then the number of cars identified as catalytic cars that are non-catalytic cars is given by $n P_{cc}$.

Let $\tilde{N}$ be the apparent number of catalytic cars observed. Then

$$B = n P_{cc}/\tilde{N}$$

Now n is unknown, but if P is reasonably small, then $n \simeq \tilde{n}$, where $\tilde{n}$ is the apparent number of non-catalytic cars observed. Therefore

$$B \simeq \tilde{n} QP/\tilde{N}$$

For P not small, a more exact value for B can be derived.

Appendix B

United States Environmental Protection Agency

Region 10
1200 Sixth Avenue
Seattle, WA 98101

EPA FUEL SWITCHING SURVEY

Region	Time (Beginning / End)	Inspection Number

STATION INFORMATION

Inspection Date	Month	Day	Year

Name of Station	Brand of Gasoline

Address of Station (Street)	Urban	Residential	Rural
City	Person in Charge		

Gasoline Price	Regular	Unleaded	Premium	Diesel	Manager

County	Zip Code	Business Telephone	Office of Manager Telephone

SURVEY INFORMATION

License Number	State	Make	Model	Passengers	Full Serve	Self Serve	Gas Type

Appendix C

Audit Results

TACOMA

DOUBLE OBSERVATIONS					INDEPENDENT RANDOM AUDITS		
Dual Obsv./ Error	Audited Vehicles	Sta. ID. No.	Total Vehicles	Dual Audit/Error	No. Observ.	Sta. ID. No.	Errors
1	1	WA-TA-0010	23	1	1	WA-TA-0002	0
	4	WA-TA-0019	27		1	WA-TA-0003	0
	2	WA-TA-0020	20	1	5	WA-TA-0006	0
	2	WA-TA-0021	18		3	WA-TA-0129	0
	2	WA-TA-0023	17		2	WA-TA-0147	0
	2	WA-TA-0025	11		3	WA-TA-0223	0
	1	WA-TA-0026	5				
	4	WA-TA-0032	15		15		0
	1	WA-TA-0033	32	2		0.0% error	
	7	WA-TA-0035	48				
	3	WA-TA-0036	3	1			
	1	WA-TA-0037	6				
	3	WA-TA-0041	15				
	1	WA-TA-0042	22	1			
	7	WA-TA-0043	35				
	2	WA-TA-0045	11				
	6	WA-TA-0051	19				
	20	WA-TA-0054	20				
	25	WA-TA-0057	25	1			
	4	WA-TA-0061	18				
	21	WA-TA-0064	21				
	3	WA-TA-0067	6				
	2	WA-TA-0071	2	1			
	2	WA-TA-0075	6				
	2	WA-TA-0089	17	1			
	4	WA-TA-0092	4				
	2	WA-TA-0095	2				
	6	WA-TA-0097	6				
	52	WA-TA-0101	52				
	19	WA-TA-0104	19				
	18	WA-TA-0105	18				
1	2	WA-TA-0111	9	1			
	27	WA-TA-0124	27				
	5	WA-TA-0133	5				
	18	WA-TA-0134	18				
	16	WA-TA-0148	16				
	12	WA-TA-0161	12				
1	13	WA-TA-0172	13	1			
	22	WA-TA-0182	22				
	6	WA-TA-0186	6				
	6	WA-TA-0231	6				
5	355		677	11			
	1.4% error			1.6% error			

Audit Results

SPOKANE

DOUBLE OBSERVATIONS					INDEPENDENT RANDOM AUDITS		
Dual Obsv./ Error	Audited Vehicles	Sta. ID. No.	Total Vehicles	Dual Audit/Error	No. Observ.	Sta. ID. No.	Errors
	30	WA-SP-02	30		6	WA-SP-02	
	4	WA-SP-07	4		6	WA-SP-08	
	41	WA-SP-08	41		41	WA-SP-145	
	6	WA-SP-33	25		46	WA-SP-203	1
	0	WA-SP-40	85		99		1
	26	WA-SP-50	26			1% error	
	3	WA-SP-65	3				
	20	WA-SP-67	20				
	14	WA-SP-68	14				
	16	WA-SP-75	16				
	7	WA-SP-76	7				
	39	WA-SP-78	39				
	14	WA-SP-82	14				
	26	WA-SP-83	26				
	29	WA-SP-85	29				
	8	WA-SP-107	8				
	15	WA-SP-108	15				
	14	WA-SP-109	14				
	16	WA-SP-114	16	1			
	21	WA-SP-128	21				
	44	WA-SP-134	44				
	41	WA-SP-145	41				
	33	WA-SP-148	33				
	2	WA-SP-177	2				
1	20	WA-SP-188	20	1			
	27	WA-SP-194	27				
1	46	WA-SP-203	46	1			
	8	WA-SP-207	8				
	16	WA-SP-210	16				
	35	WA-SP-222	35				
2	26	WA-SP-226	26	3			
4	647		751	6			
	0.6%		0.8%				

Audit Results

SEATTLE

DOUBLE OBSERVATIONS					INDEPENDENT RANDOM AUDITS		
Dual Obsv./ Error	Audited Vehicles	Sta. ID. No.	Total Vehicles	Dual Audit/Error	No. Observ.	Sta. ID. No.	Errors
	60	WA-SE-16	60		6	WA-SE-67	
	48	WA-SE-22	48				
	16	WA-SE-23	16				
	8	WA-SE-27	12				
	16	WA-SE-34	20				
	38	WA-SE-38	38				
	48	WA-SE-60	48				
2	49	WA-SE-62	49	2			
	69	WA-SE-67	69				
	56	WA-SE-74	56				
	8	WA-SE-79	8				
	62	WA-SE-83	62				
	14	WA-SE-102	14				
2	25	WA-SE-104	25	1			
	49	WA-SE-109	49				
	54	WA-SE-131	54				
	67	WA-SE-132	67				
	37	WA-SE-139	37				
	22	WA-SE-147	22				
	32	WA-SE-154	32				
	4	WA-SE-159	42				
	39	WA-SE-170	39				
	1	WA-SE-188	30				
	23	WA-SE-190	23				
	4	WA-SE-192	10				
	25	WA-SE-194	25				
	13	WA-SE-195	27				
	43	WA-SE-288	43				
	21	WA-SE-289	21				
	32	WA-SE-500	32				
	4	WA-SE-501	4				
4	987		1082	3			
	0.4% error		0.3% error				

Audit Results

EUGENE

DOUBLE OBSERVATIONS					INDEPENDENT RANDOM AUDITS		
Dual Obsv./ Error	Audited Vehicles	Sta. ID. No.	Total Vehicles	Dual Audit/Error	No. Observ.	Sta. ID. No.	Errors
	8	OR-EU-0002	8		3	OR-EU-0011	
	12	OR-EU-0027	12		1	OR-EU-0018	
	1	OR-EU-0041	1		2	OR-EU-0031	
	16	OR-EU-0042	16		5	OR-EU-0033	
	9	OR-EU-0055	9		5	OR-EU-0066	1
	39	OR-EU-0062	39		5	OR-EU-0088	
	8	OR-EU-0063	8		6	OR-EU-0089	
	6	OR-EU-0065	38		27		1
	14	OR-EU-0068	14				
	16	OR-EU-0076	16				
	10	OR-EU-0078	10				
1	8	OR-EU-0079	8				
	4	OR-EU-0082	4	1			
	13	OR-EU-0094	13				
	16	OR-EU-0098	16				
1	180		212	1			
	0.6% error		0.5% error				

Audit Results

PORTLAND

DOUBLE OBSERVATIONS					INDEPENDENT RANDOM AUDITS		
Dual Obsv./ Error	Audited Vehicles	Sta. ID. No.	Total Vehicles	Dual Audit/Error	No. Observ.	Sta. ID. No.	Errors
	4	OR-PO-22	48		5	OR-PO-00	
	3	OR-PO-42	21		4	OR-PO-02	
	5	OR-PO-78	58		5	OR-PO-05	
	9	OR-PO-101	9		5	OR-PO-17	
	6	OR-PO-107	6		2	OR-PO-47	
	47	OR-PO-110	43		4	OR-PO-69	
	13	OR-PO-124	12		1	OR-PO-70	
	17	OR-PO-159	17		5	OR-PO-76	
	17	OR-PO-187	17		3	OR-PO-80	
	8	OR-PO-199	8		5	OR-PO-139	
	5	OR-PO-201	24		5	OR-PO-176	
	3	OR-PO-220	13		6	OR-PO-205	
	5	OR-PO-271	29		3	OR-PO-295	
	2	OR-PO-333	26		3	OR-PO-340	
	9	OR-PO-335	21		3	OR-PO-346	
1	28	OR-PO-374	30		3	OR-PO-382	
	5	OR-PO-380	28		2	OR-PO-415	
	6	OR-PO-412			74		
1	192					0.0% error	

1.04 % error

Audit Results

BOISE

DOUBLE OBSERVATIONS					INDEPENDENT RANDOM AUDITS		
Dual Obsv./ Error	Audited Vehicles	Sta. ID. No.	Total Vehicles	Dual Audit/Error	No. Observ.	Sta. ID. No.	Errors
	10	ID-BO-48	10		2	ID-BO-01	
	6	ID-BO-72	16		2	ID-BO-04	
	6	ID-BO-79	6		1	ID-BO-17	
	6	ID-BO-96	12		5	ID-BO-43	
	10	ID-BO-102	10		8	ID-BO-138	
	10	ID-BO-107	10		6	ID-BO-388	
	21	ID-BO-111	21		2	ID-BO-1015	
	7	ID-BO-217	57		3	ID-BO-004	
	6	ID-BO-277	56		1	ID-BO-09	
	2	ID-BO-1050	2		30		0
	6	ID-BO-79	7			0.0% error	
0	90		207	0			
	0.0% error		0.0% error				

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STATISTICAL DESIGN AND METHODOLOGY FOR THE ANALYSIS OF THE 1979 REGION X FUEL SWITCHING SURVEY

TSC-PD-A223-4

March 1980

Peter Bickel
Leo Breiman

Contract No. 68-01-5086
Task 4

Submitted to:

U.S. Environmental Protection Agency
401 M Street, S.W.
Washington, D.C. 20460

Task Officer: Mel Kollander

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1. INTRODUCTION

Under contract number 68-01-5086, Technology Service Corporation was requested to provide statistical support to the personnel of the Environmental Protection Agency, Region X, in the design and analysis of a fuel switching survey to be carried out by gas station observations during 1979. The personnel involved in this project were Drs. Peter Bickel and Leo Breiman. Leo Breiman assisted in the design of a randomized survey and conferred with Region X personnel on methods of auditing for data quality. The design is described in Section 2. A careful statistical analysis of the data was carried out to determine:

1. Confidence intervals for the fuel switching rates. (Leo Breiman)
2. The effect of factors such as city, type of service, price differential, etc., on fuel switching rates. (Peter Bickel)

Some brief summary conclusions of this analysis are given in Section 3.

By the very nature of the phenomenon being studied, the survey design did not fit into the mold of one of the usual sampling designs. Therefore, the statistical techniques necessary to analyze the results were not standard. Appropriate techniques for the analysis had to be specially derived. The description of these techniques, the derivation of the equations, and the details of the analysis are given in Appendices A and B. The results may be important if future fuel switching surveys are planned.

This present report is deliberately limited in its scope to cover only those areas in which Technology Service Corporation was involved. A

detailed description of the field study, the survey methods used, the practical aspects of the survey, and a detailed data description will be released by Region X. After many hours of checking into their data quality control methods and general field operations, we are satisfied that excellent data quality standards have been observed by the survey personnel. We want to compliment the Region X personnel involved in the survey, especially William Schmidt and Douglas Smith, for their open and cooperative attitude which made it easier for us to contribute to the quality of the survey. Also, for their dedicated concern that the survey be the best possible within the limits of their resources.

2. BACKGROUND AND DESIGN

In the usual fuel switching surveys, a team or teams visit an urban area, make observations at service stations, and determine how many of the observed cars that should be taking unleaded gas are actually taking leaded gas. This is generally done by noting the type of gas purchased and the license numbers of the vehicles. The license number is submitted to the state Department of Motor Vehicles (DMV) to get a description of the vehicle; that description is used to determine whether the vehicle is designed to take unleaded gas.

The population being sampled from needs a careful definition. The urban area has to be defined, as do the length of the team visit and its hours of observation. The underlying population is the set of all fueling visits to service stations in the area made by cars designed for unleaded gas during the designated observation period of the team. The population parameter to be estimated is the proportion R* of these visits that resulted in a switch to leaded gas.

There are two major types of errors arising in such a survey:

1. Systematic errors including observer error, DMV errors and license-plate switching.
2. Sampling errors, bias in sampling plan, random sampling error.

The extent of the systematic errors can be estimated by procedures which include:

- Independent observers.
- Observer descriptions of make, model, year of vehicle to check against the DMV description.

3. Descriptions of stationary vehicles, i.e., parking lot descriptions checked against DMV returned descriptions.

Some of these procedures were used in the Region X survey and are described in their report. Either the systematic errors are kept to within negligibly small bounds, or they need to be reliably estimated and compensated for in the final switching estimate.

In prior surveys, teams drove around until they encountered service stations and then observed. This made the sampling plan difficult to analyze and introduced unknown sampling biases. In the present survey, a more systematic plan was used. Phone books covering the areas defined were obtained. At times, as in Seattle, more than one phone book was required. Service stations were selected at random without replacement from the yellow pages, using a table of random numbers. At times a service station was listed twice, once individually and once under the name of a major oil company. In this case, a fair coin was tossed (using the table of random numbers) and the station included in the selection if the result was heads, otherwise not.

The survey team went down the list of selected stations and visited four a day, spending 1.5 hours observing at each one. At least, this was the theoretical framework. Some modifications were made to make the plan more feasible. To keep the travel time within reason, the randomly selected stations were grouped into 3 or 4 subgroups by geographic proximity. The daily route observed 4 stations within the same subgroup. In addition, in the Seattle area, there was a continuing gas shortage, with long lines and stations open only a few hours a day. When closed stations were encountered,

they were later revisited, with the exception that if there was an open station on the same intersection as the closed station, it was substituted for the station.

A few stations were observed for time periods shorter than 1.5 hours. When this occurred, the relevant counts were multiplied by the ratio (1.5/ hours observed).

The design of the survey was not perfect, but it was a step in the right direction. Any design has to compromise between the limitations of survey resources and theoretically more desirable goals. We must emphasize that probably the most important potential source of error is not in the sampling design, but in observer error. Unless all possible steps are taken to minimize or estimate observer error the most sophisticated design is worthless in terms of statistical validity.

Further improvements in the present design can be made. We suggest a standardized two-week (10-day),30-station survey plan for urban areas. Use standardized survey times such as 8:00AM to 10:30AM, 11:30AM to 2:00PM, 3:00PM to 5:30PM. Draw the thirty stations at random from a frame of stations for the area and sequentially assign them (as drawn) to the 30 time slots in the survey period. Leave enough travel time to go between any two pairs of stations. However, if, in addition to estimating R^*, a study of the effects of various factors is desired, then the number of stations sampled will have to be increased.

3. SOME SUMMARY CONCLUSIONS

During 1979, the survey team visited six areas. Using the survey methodology referred to in the preceding section, service stations were selected for observation. The numbers of stations observed were:

City	No. of Stations Observed
Boise	87
Eugene	80
Portland	95
Seattle	61
Spokane	31
Tacoma	78
TOTAL	432

In all, a total of about 9,000 vehicles were observed, or about 21 vehicles per station. Of these 9,000, about 3,000 were identified as requiring unleaded gas. About 4,500 vehicles were identified as not requiring unleaded gas. Fuel requirements for another 1,600 vehicles could not be identified for the following reasons:

No. Not Identified	Reason
407	No file in DMV
556	Unable to determine fuel requirements from DMV records.
222	Out-of-state license plate not checked yet.
393	Could not see license plate.

In addition to a description of each observed vehicle, some characteristics of each observed service station were recorded, i.e., price differentials between various types of fuels, type of station ownership, and service offered (i.e., self service, full service, etc.).

Technology Service Corporation was given the completed data file and asked by Region X to do two tasks:

First: For each urban area, estimate the rate of fuel switching and computer confidence intervals for the estimates.

Second: Examine the effects of a number of factors on the fuel switching rates.

Regarding the latter analysis, the relevant factors were in two groups:

1. Service station characteristics
2. Vehicle characteristics

The sorting-out of the effects of vehicle characteristics was sized up as a difficult task. For instance, a description of a vehicle as a Ford Sedan could include either a sedate family car or a high-performance V8 tire squealer. Furthermore, the individual vehicle descriptive data tended to be spotty. Therefore, the analysis of the association of fuel switching with individual vehicle characteristics was not undertaken. If desired, it can be done at a future date.

As previously mentioned, neither of these two above tasks could be done by straightforward applications of known statistical models. Therefore, a technical framework had to be specially built. The derivation

of the confidence intervals is given in Appendix A. In particular, page 13 gives the formula used for the 95% confidence interval computation. With these formulas, the data was used to compute estimates of R^* and 95% confidence intervals for each of the six urban areas surveyed.

It is important to keep in mind the definition of the parameter R^* being estimated. It is NOT the proportion of drivers that are fuel switchers neither is it the proportion of vehicles that are using the wrong fuel. R^* is the proportion of all service-station visits by catalytic-converter-equipped vehicles in the urban area during the observation period that results in the purchase of leaded gasoline. With this definition R^* can be estimated by the survey. Table 1 below gives a summary of the resulting estimates and 95% confidence intervals.

TABLE 1. SUMMARY BY CITY

City	R* Estimate(%)	95% Confidence Intervals
Boise	18.1	(13.7, 22.5)
Eugene	8.4	(5.2, 11.6)
Portland	6.0	(4.3, 7.7)
Seattle	7.9	(5.2, 10.6)
Spokane	7.3	(3.5, 11.1)
Tacoma	4.8	(2.3, 7.2)

The Region X report will give more background on the high estimated R^* for Boise. With the exception of Boise, all confidence intervals overlap

Because of this, we decided to merge the Oregon-Washington data and produce an overall estimate and confidence interval based on the five urban areas. The result was:

Estimated R*(%)	95% Confidence Interval(%)
6.9	(5.7, 8.1)

Next, we analyzed the effects of the following service-stations characteristics:

Location: Which of the six sites the stations were located in.

Price Differential: The difference in price per gallon between unleaded and regular gasoline.

Service: Self service or full service.

Major/Minor: Classification according to membership of the oil company in the seven major oil companies or as a minor oil company.

Because of possible interactions between these factors (i.e., no self service in Portland), it might not be appropriate to analyze the effect of each factor separately. Therefore, a method was developed for looking at the effects of various combinations of factors in a four-dimensional χ^2 analysis. The discussion of the statistical model and derivations of the various statistical tests are given in Appendix B. The overall qualitative conclusions of the analysis are:

1. There is strong evidence that the switching proportion depends on the city under study or, at least, that Boise is different.

2. There is weak evidence that, in addition, the proportion of switches is higher at self- than full-service stations.

3. There is no evidence that price difference or major/minor classification plays a role, but a substantially larger, carefully stratified survey would be needed for further analysis.

Appendix A

COMPUTATION OF ESTIMATES, BIASES, VARIANCES AND CONFIDENCE INTERVALS

by Leo Breiman

The statistical framework is as follows: Let there be a population S of service stations s in a given urban area. Denote by J the total number of 1.5-hour observation periods and number these by j = 1, 2, ..., J. Let $Y_j(s)$ be the number of visits of unleaded gas cars to station s during the jth period, and let $X_j(s)$ be the number of the $Y_j(s)$ that switched to leaded gas, so that $X_j(s) \leq Y_j(s)$. The population parameter we will estimate

$$R^* = \sum_s \sum_{j=1}^{J} X_j(s) \Big/ \sum_s \sum_{j=1}^{J} Y_j(s)$$

That is, R* is the proportion of all visits to service stations listed in the telephone directory of the area that resulted in fuel switching. Two notes: The total population of service stations in the area may differ from the population listed in the telephone directory. Some stations may not list in the yellow pages. But this was the only frame readily available. Secondly, the observation periods generally covered the daylight hours beginning at 8:00AM and ending at 6:00PM and half of the weekend daylight hours. There were periods of travel time between stations. But there is no plausible reason to believe that the

proportion of fuel switching in the travel time periods differed from the proportion in the observed periods. Therefore, a reasonable interpretation of R* is that it is the proportion of daylight visits to service stations in the frame during the period of the team's visit to the area that resulted in switching.

Conceptually, the sampling plan can be modeled by assuming that J stations were selected, without replacement, from the frame S, and the jth station selected s_j^* was observed in the jth interval. Let

$$X_j = X_j(s_j^*) \quad \text{and} \quad Y_j = Y_j(s_j^*)$$

be the number of observed switches and visits, respectively, in the jth period and denote

$$\hat{X} = \sum_{j=1}^{J} X_j, \qquad \hat{Y} = \sum_{j=1}^{J} Y_j \quad ,$$

so that $\hat{X}$ is the total number of observed switches, and Y the total number of observed visits by cars designed for unleaded gas. The estimate we use for R^* is

$$\hat{R} = \hat{X}/\hat{Y} \quad ,$$

which is a ratio estimate and is generally biased. However, letting the total number of stations in the frame be N, note that

$$E\hat{X} = \frac{1}{N} \sum_{s} \sum_{j} X_j(s)$$

$$E\hat{Y} = \frac{1}{N}\sum_{s}\sum_{j} Y_j(s)$$

so that

$$R^* = E\hat{X}/E\hat{Y} \quad ,$$

where E denotes expectation.

In the following section, approximate bounds for the variance and bias of $\hat{R}$ are derived. The bounds for the bias are derived under two different sets of assumptions. When the two bounds were computed using the sample data, both resulted in values so small as to be negligible. The approximate bound for the variance is

$$\mathrm{Var}(\hat{R}) \leq \frac{1}{Y^2}\sum_{j}(X_j - \hat{R}Y_j)^2$$

This result is similar to the standard variance computation for ratio estimators. See, for example, W. C. Cochran, Sampling Techniques, Wiley, 1953, pp. 22-23.

In fact, the survey structure is similar to a household survey. Suppose there is a population of N households (service stations); n of them are selected at random without replacement, and the jth household has Y_j members of whom X_j are switchers. The purpose is to estimate the overall proportion of switchers.

The difference between the present survey and a standard household survey is that for each household, the values of Y_j and X_j change over

the J observation periods. Therefore, the present survey can be conceived of as a household study in which a household is selected from the population of all households and then a period j is selected without replacement from the set J of all observation periods to observe the selected household.

Making the usual assumption that the ratio $\hat{R}$ has an approximately normal distribution, the 95% confidence intervals were taken to be

$$\hat{R} \pm 2\sqrt{V(\hat{R})}$$

and the bound given above was used in the computation.

A.1 VARIANCE AND BIAS COMPUTATIONS

Now the problem becomes to derive bounds for the bias and variance of the estimate $\hat{R}$. First, we work on the variance. Let

$$V = E\left[\frac{\hat{\bar{X}}}{\hat{\bar{Y}}} - E\left(\frac{\hat{\bar{X}}}{\hat{\bar{Y}}}\right)\right]^2 .$$

Denote the bias by b. Then we note that

$$MSE = E\left(\frac{\hat{\bar{X}}}{\hat{\bar{Y}}} - R^*\right)^2 = V + b^2 .$$

It is easier to compute

$$MSE = E\left(\frac{\hat{\bar{X}}}{\hat{\bar{Y}}} - R^*\right)^2$$

and subtract b^2 than to estimate V directly. Hence, we will work on getting bounds for the MSE. Write

$$MSE = E\left(\frac{\hat{X}-\hat{Y}R^*}{\hat{Y}}\right)^2$$

Using a customary aproximation

$$MSE = \frac{E(\hat{X}-\hat{Y}R^*)^2}{(E\hat{Y})^2}$$

As usual, we replace $E\hat{Y}$ by the sample value $\hat{Y}$, and work on the numerator Write

$$\hat{X} \quad \hat{Y}R^* = \sum_j (X_j - R^* Y_j)$$

and define

$$Z_j(s) = X_j(s) - R^* Y_j(s), \qquad Z_j = Z_j(s_j^*)$$

Then

$$E(\hat{X} - \hat{Y}R^*)^2 = E\left(\sum_j Z_j\right)^2$$

$$= \sum_j EZ_j^2 + \sum_{k \neq j} EZ_j Z_k \quad .$$

Now, for $j \neq k$

$$EZ_jZ_k = \frac{1}{N(N-1)} \sum_{s \neq s'} Z_j(s)\, Z_k(s')$$

$$= \frac{N}{N-1}\left[\frac{1}{N^2} \sum_{s,s'} Z_j(s)\, Z_k(s') - \frac{1}{N^2}\sum_s Z_j(s)\, Z_k(s)\right]$$

so

$$EZ_jZ_k = \frac{N}{N-1}\,(EZ_j)(EZ_k) - \frac{1}{N(N-1)}\sum_s Z_j(s)\, Z_k(s)$$

Using the fact that $\sum_j EZ_j = 0$ gives

$$E\left(\sum_j Z_j\right)^2 = -\frac{N}{N-1}\sum_j (EZ_j)^2 + \sum_j EZ_j^{\,2} - \frac{1}{N(N-1)}\sum_s \sum_{j \neq k} Z_j(s)\, Z_k(s)$$

Define

$$Z(s) = \sum_j Z_j(s)$$

so that

$$E\left(\sum_j Z_j\right)^2 = \sum_j \mathrm{Var}(Z_j) - \frac{1}{N-1}\sum_j (EZ_j)^2$$

$$- \frac{1}{N(N-1)}\sum_j Z(s)^2 + \frac{1}{N(N-1)}\sum_s \sum_j Z_j^2(s)$$

$$= \frac{N}{N-1}\sum_j \mathrm{var}(Z_j) - \frac{1}{N(N-1)}\sum_s [Z(s)]^2$$

$$\leq \frac{N}{N-1}\sum_j \mathrm{var}(Z_j)$$

$$\leq \frac{N}{N-1}\sum_j EZ_j^2 \quad . \qquad \text{(A-1)}$$

Replace $\sum_j EZ_j^2$ with the sample value

$$\sum_j (X_j \quad \hat{R}Y_j)^2$$

to get the approximate bound

$$V \leq \frac{1}{\hat{Y}^2}\sum_j (X_j - \hat{R}Y_j)^2 \quad . \qquad \text{(A-2)}$$

One additional possible assumption is that the J values $V_j = JZ_j$ are samples from I's [illegible] fact

$$E\left(\frac{1}{J}\sum_j V_j\right) = \frac{1}{N}\sum_s Z(s)$$

Then an estimate for

$$\frac{1}{N}\sum_s Z^2(s)$$

is given by

$$\frac{1}{J}\sum_j V_j^2 = J\sum_j Z_j^2$$

Using this in (A-2) gives the more familiar bound

$$V \leq \frac{1-f}{\hat{Y}^2}\sum_j (X_j - \hat{R}Y_j)^2 \qquad \text{(A-3)}$$

where

$$f = J/N-1$$

However, this assumption is not an altogether comfortable one, and our opinion is that (A-1) is a sounder value.

The bias computation is more complicated. Write

$$\frac{\hat{X}}{\hat{Y}} = \frac{\hat{X}}{E\hat{Y}+(\hat{Y}-E\hat{Y})} \simeq \frac{\hat{X}}{E\hat{Y}}\left(1 - \frac{\hat{Y}-E\hat{Y}}{E\hat{Y}}\right)$$

Taking expectations gives

$$E\left(\frac{\hat{X}}{\hat{Y}}\right) \approx R^* - \frac{\Gamma(\hat{X},\hat{Y})}{(E\hat{Y})^2} \quad ,$$

where Γ denotes covariance. So, to a first approximation

$$b = \frac{\Gamma(\hat{X},\hat{Y})}{(E\hat{Y})^2} \quad .$$

As before, use the approximation

$$E\hat{Y} \approx \hat{Y} \quad ,$$

so that

$$b \approx \frac{1}{(\hat{Y})^2}\,\Gamma(\hat{X},\hat{Y})$$

Now

$$\Gamma(\hat{X},\hat{Y}) = \sum_{j,k} \Gamma(X_j, Y_k)$$

For $j = k$, using the following expression

$$\Gamma(X_j,Y_k) = \left[\frac{1}{N(N-1)} \sum_{s'\neq s} X_j(s)\, Y_k(s')\right] - (EX_j)(EY_k)$$

a computation gives

$$\Gamma(X_j,Y_k) = \frac{1}{(N-1)}(EX_j)(EY_k) - \frac{1}{N(N-1)}\sum_s X_j(s)\ Y_k(s)$$

For $j = k$,

$$\Gamma(X_j,Y_j) = \frac{1}{N}\sum_s X_j(s)\ Y_j(s) - (EX_j)(EY_j)$$

Therefore, defining

$$X(s) = \sum_j X_j(s), \qquad Y(s) = \sum_k Y_k(s)$$

$$\Gamma(\hat{X},\hat{Y}) = \sum_j \Gamma(X_j,Y_j) + \frac{1}{N-1}\left(\sum_j EX_j\right)\left(\sum_k EY_k\right)$$

$$- \frac{1}{N-1}\sum_j (EX_j)(EY_j) - \frac{1}{N(N-1)}\sum_s X(s)Y(s)$$

$$+ \frac{1}{N(N-1)}\sum_j\sum_s X_j(s)\ Y_j(s)$$

Simplifying this gives

$$\Gamma(\hat{X},\hat{Y}) = \frac{N}{N-1}\sum_j \Gamma(X_j,Y_j) + \frac{1}{N-1}(E\hat{X})(E\hat{Y}) - \frac{1}{N(N-1)}\sum_s X(s)Y(s)$$

There are two sets of assumptions that can lead to estimates of the bias. The first, and more stringent, is that

Assumption I:

$$\sum_j \Gamma(X_j, Y_j) \geq 0$$

The rationale for this assumption is that there usually is a positive dependence between X_j and Y_j. That is, the larger the number of visits to a station, then the larger (generally) the number of switches at that station. Under this assumption,

$$\Gamma(\hat{X}, \hat{Y}) \geq \frac{1}{N-1}(E\hat{X})(E\hat{Y}) - \frac{1}{N(N-1)} \sum_j X(s)Y(s) \qquad \text{(A-4)}$$

Without any assumptions, we have

$$\Gamma(\hat{X}, \hat{Y}) \leq \frac{N}{N-1} \sum_j E(X_j Y_j) + \frac{1}{N-1}(E\hat{X})(E\hat{Y})$$

Define

$$\bar{X}(s) = \frac{1}{J} \sum_j X_j(s)$$

$$\bar{Y}(s) = \frac{1}{J} \sum_j Y_j(s)$$

and assume, in addition, that

Assumption II:

$$\sum \frac{1}{J} \sum [X_j(s) - \bar{X}(s)][Y_j(s) - \bar{Y}(s)] > 0$$

This is a weaker assumption. Its meaning is that at a fixed station (generally) there is a positive dependence over time between number of visits and number of switches. The above assumption can be rewritten as

$$\sum_{s} X(s)Y(s) \leq J \sum_{j,s} X_j(s)Y_j(s)$$

substituting this into (A-4), page 20, gives

$$\Gamma(\hat{X},\hat{Y}) \geq \frac{1}{N-1} (E\hat{X})(E\hat{Y}) - \frac{J}{N-1} \sum_{j} E(X_j Y_j)$$

Replacing expressions by corresponding sample expressions gives

$$\Gamma(\hat{X},\hat{Y}) \geq \frac{1}{N-1} \hat{X}\ \hat{Y} - \frac{J}{(N-1)} \sum_{j} X_j\ Y_j$$

and

$$\Gamma(\hat{X},\hat{Y}) \leq \frac{N}{N-1} \sum_{j} X_j Y_j + \frac{1}{N-1} \hat{X}\ \hat{Y}$$

There is another approach which substitutes a different first assumption. If we keep Assumption II, then start with

$$\Gamma(\hat{X},\hat{Y}) \geq \frac{N}{N-1} \sum_{j} \Gamma(X_j,Y_j) + \frac{1}{N-1} (E\hat{X})(E\hat{Y}) - \frac{J}{N-1} \sum_{j} E(X_j Y_j)$$

Put $R_j = EX_j/EY_j$ and write

$$X_j - EX_j = X_j - R_jY_j + R_j(Y_j - EY_j)$$

so that

$$r(X_j,Y_j) = E[(X_j - R_jY_j)Y_j] + R_jVar(Y_j)$$

Now define Assumption I to be

$$R_j = R^*$$

Then

$$r(X_j,Y_j) = EZ_jY_j + R^*Var(Y_j)$$

so that

$$\sum_j r(X_j,Y_j) \geq EZ_jY_j$$

Using sample estimates

$$r(\hat{X},\hat{Y}) \geq \frac{1}{N-1}\hat{X}\hat{Y} + \frac{N}{N-1}\sum_j (X_j - \hat{R}Y_j)Y_j - \frac{1}{N-1}\sum X_jY_j$$

Combining the above, we have, without assumptions, that

$$b \geq -\frac{1}{N-1}\hat{R} + \frac{J}{(N-1)\hat{Y}^2}\sum_j X_jY_j$$

Under Assumptions I and II

$$b \leq -\frac{1}{N-1}\hat{R} + \frac{J}{(N-1)\hat{Y}^2}\sum_j X_j Y_j$$

Under Assumption I' and II

$$b \leq -\frac{1}{N-1}\hat{R} + \frac{J}{(N-1)\hat{Y}^2}\sum_j X_j Y_j - \frac{N}{(N-1)\hat{Y}^2}\sum_j (X_j - \hat{R}Y_j)Y_j$$

The advantage of Assumption I' is that it can be tested using the day. The service stations observed can be grouped in four subsets, depending on whether they were observed 1st, 2nd, 3rd or 4th during the day. Denote these subsets by C_1, C_2, C_3, C_4. For each subset define

$$\hat{Y}_k = \sum_{j\varepsilon C_k} Y_j, \qquad \hat{X}_k = \sum_{j\varepsilon C_k} X_j$$

Then the issue is whether the $\hat{R}_k = \hat{X}_k/\hat{Y}_k$ can be consisered as approximately equal. This can be framed statistically as: Define the four sets of variables

$$U_{j,k} = \hat{X}_j/\hat{Y}_k, \quad j\varepsilon C_k, \quad k = 1,2,3,4$$

When do the four sets come from the same underlying population versus shift alternatives? Although for fixed k, the $U_{j,k}$ are not quite independent, independence is a reasonable first approximation and standard tests can be applied; in particular, the Kruskal-Wallis test is an appropriate candidate.

In our computations on the bias bounds, both sets of bounds produced the conclusion that the bias was negligible. (See Table A-1, following.)

TABLE A-1

City	First Bias Bound	Second Bias Bound
Boise	.002	.002
Eugene	.0006	.0004
Portland	.00004	-.00003
Seattle	.00003	-.0001
Spokane	.0002	-.0002
Tacoma	.0001	-.00003

Appendix B

ANALYSIS OF SERVICE STATION LOCATION AND CHARACTERISTICS ON FUEL SWITCHING

by Peter Bickel

In this appendix we analyze the effect of different characteristics of service stations on the proportion of visits to these stations resulting in switching. The characteristics (factors) considered were:

City: Which city the stations were located in

Price Differential: The difference in price per gallon between unleaded and regular gasoline

Service: Self service or full service

Major/Minor: Classification according to membership of the oil company in the seven major oil companies (according to J. M. Blair, The Control of Oil, Pantheon Publishers)

The categories (levels) of the factors and their number were:

City (6) Boise, Eugene, Portland, Seattle, Spokane, and Tacoma

Price (3) up to 5¢, over 5¢, and difference unknown

Service (2)*Self or full service

Major/Minor(3) Major, minor and category unknown

As usual, we call the collection of all service stations corresponding to a particular combination of levels a cell--for instance, all stations in Boise, with a price difference of over 5¢, offering full service and representing a major oil company. There are a total of 69 out of the 108 possible for which at least one representative appeared

*Full- and self-service departments of the same station were treated as separate stations.

in the sample. Twenty-five of the missing 39 cells corresponded to "missing value" categories in the price and major-minor classification, 8 to the lack of self-service stations in Portland and Eugene. Unfortunately, in addition to these 8 missing cells there are 11 cells in which there are 4 or fewer visits (out of a total of 2546). This lack of balance combined with low switching rates makes conclusive analysis difficult. Our decision is based on a simplification of the model introduced in Appendix A of this report by Leo Breiman (hereinafter referred to as (B)). (B) associated with the sampling universe of all fueling visits to stations in the area (made by candidate cars) a parameter R^*, the proportion of all visits that resulted in switchings. Write

$$R^* = \sum_s \pi^*(s)\, R^*(s)$$

where (in the notation of (B))

$$\pi^*(s) = \frac{\sum_{j=1}^{J} X_j(s)}{\sum_s \sum_{j=1}^{J} X_j(s)}$$

$$R^*(s) = \sum_{j=1}^{J} Y_j(s) \Big/ \sum_{j=1}^{J} X_j(s)$$

are, respectively, the proportion of visits to station s and the proportion of fuel switchers among visitors to s. The parameters we are interested in studying are, for each cell, the proportion of switches among visits to stations in the cell:

$$R^*(\text{cell}) = \sum\{\pi^*(s)\, R^*(s):\ s \in \text{cell}\} \Big/ \sum\{\pi^*(s):\ s \in \text{cell}\}$$

We prefer to interpret these quantities in a more universal framework as:

$\pi^*(s)$ = probability that during a randomly selected 1.5-hour daylight observation period a randomly selected car intends to refuel at station s.

$R^*(s)$ = conditional probability that a car refueling at station s will be a switcher.

Thus

$R^*(\text{cell})$ = (conditional) probability that a car refueling at a station in the cell is a switcher.

Let's write:

$$R^*(A) = \sum\{R^*(s) : s \in A\}$$

for the proportion of switches in the stations falling in A. For instance, R*(Boise) would be the proportion of switches in Boise.

I. Testing: Our first aim is to study the variation of R*(cell) as we vary the levels of the factors in each cell. Specifically, we want to test the 15 hypotheses:

(0,0,0,0): R*(cell) = constant (none of the factors matter)

(1,0,0,0): R*(cell) depends only on city (=R*(city))

(1,1,0,0): R*(cell) depends only on city and price = R*(city, price)

We base our tests on (using (B's) notation):

$$\hat{X}(\text{cell}) = \sum\{X_j(s_j^*): s_j^* \in \text{cell}\}$$

$$\hat{Y}(\text{cell}) = \sum\{Y_j(s_j^*): s_j^* \in \text{cell}\}$$

which are the observed number of visits and of switches for stations in the cell. (We'll also write $\hat{R}(\text{cell}) = \hat{Y}(\text{cell})/\hat{X}(\text{cell})$, etc.) To proceed we make two assumptions:

(B) Assumption 1': The probability that a car refueling at s during observation period j is a switcher does not depend on j.

Homogeneity: $R^*(s) = R^*(\text{cell})$ for all $s \in$ cell. This is just the hypothesis that our categorization is sufficiently fine so that we can expect homogeneity among stations in a cell.

The second assumption is somewhat questionable, especially for the "missing value" cells. However, it is necessary for dealing with the many cells in which very few stations (often only 1) were represented in the survey so that the (B) bias and variance approximations cannot realistically be applied to $\hat{Y}(\text{cell})/\hat{X}(\text{cell})$.

Under these assumptions it follows that, given $\hat{X}(\text{cell})$, $\hat{Y}(\text{cell})$ has a binomial $(\hat{X}(\text{cell}); R^*(\text{cell}))$ distribution and the hypothesis that interests us can, in principle, be tested using χ^2 tests for the homogeneity of the binomial distribution.*

*See, for example, R. Pothof and M. Whittinghill, "Testing for homogeneity," Biometrika, Vol. 53, 1969, p. 167.

Such tests are of the form,

$$\frac{[\hat{R}(\text{cell}) - \hat{R}_H(\text{cell})]^2}{\hat{\text{Var}}(\text{cell})}$$

where $\hat{R}_H(\text{cell})$ is the "expected" value of $\hat{R}(\text{cell})$ under H, and $\hat{\text{Var}}(\text{cell})$ is an estimate of the variance of $\hat{R}(\text{cell})$. The most frequently used estimate is:

$$\hat{\text{Var}}(\text{cell}) = \hat{X}(\text{cell})\ \hat{R}_H(\text{cell})[1-\hat{R}_H(\text{cell})]$$

We use

$$\hat{X}(\text{cell})\ \hat{R}(\text{cell})\ 1-\hat{R}(\text{cell})^*$$

because this is more convenient when we are looking at tests of nested hypotheses as in this case. These denominators tend to be smaller in sparse tables, such as ours. So if these χ^2 tests are not significant, the more common ones will not be either. The statistics are referred to χ^2 distributions with (# degrees of freedom) = (# of (feasible) cells) - (# of parameters fitted). Table B-1 gives the 15 hypotheses, the associated d.f., χ^2 statistics and significance probabilities.

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*$\hat{R}(\text{cell})$ is replaced by $1/2\hat{X}(\text{cell})$ if $\hat{Y}(\text{cell}) = 0$.

TABLE B-1

Hypothesis	χ^2	d.f.	p-value
1 1 1 0	30.3361	39	0.8379
1 1 0 1	11.9809	20	0.9167
1 1 0 0	44.0514	51	0.7465
1 0 1 1	36.7605	42	0.7040
1 0 1 0	47.5382	59	0.8568
1 0 0 1	45.7393	52	0.7205
1 0 0 0	54.7259	63	0.7638
0 1 1 1	66.7913	51	0.0658
0 1 1 0	79.4309	63	0.0773
0 1 0 1	91.6096	60	0.0043
0 1 0 0	100.7107	66	0.0030
0 0 1 1	79.6611	63	0.0747
0 0 1 0	83.0529	67	0.0876
0 0 0 1	96.9912	66	0.0065
0 0 0 0	104.4828	68	0.0023

Factors are:

Column 1: City

Column 2: Price

Column 3: Service

Column 4: Major/Minor

The simplest hypothesis that is acceptable is that R* depends only on city ($p = .76$ on 63 d.f.). There is some evidence that service status may play a role since the hypotheses that only city matters has a significance probability of .125 on 4 d.f. under the blanket hypothesis that only city and service type can matter. There is no evidence that any other factors play a role.

The χ^2 tests have to be taken with a grain of salt, since there are several cells for which $\hat{x}$(cell) = 1 and ($\hat{R}_H$ is of the order .1), not to mention the fallibility of our assumptions. However,

1. The difference in significance probabilities between hypotheses in which city (and to some extent service) is fitted and the others is very sharp.

2. Residual analysis (see below) does not indicate any anomalies connected with factors other than city and service.

ANALYSIS OF CITY AND SERVICE EFFECTS

In Table B-2, we give $\hat{R}$(city) and $\hat{R}$(city, self service), $\hat{R}$(city, full service) as well as the associated standard deviations of these quantities computed according to (B).* These figures suggest:

1. That Boise is different from other cities.

2. That there is evidence for the notion that switching occurs more frequently in self-service than in full-service stations.

To investigate further, we formed a confidence interval for the contrast, Δ = R*(Boise) - R* (cities other than Boise). We find:

$$\hat{\Delta} = .112$$

$$SD(\hat{\Delta}) = .022 \quad .$$

To obtain a 95% confidence interval which allows for our data snooping on the $\hat{R}$(city) we use the Scheffe interval $\hat{\Delta} \pm 3.31\ SD(\hat{\Delta})$ where 3.31 is the square root of the 95% point of X^2_5. We obtain [.04..182], which implies that the proportion of switches in Boise is higher than in the other cities.

On the other hand 95% confidence intervals for all other differences in mean switching rates between cities cover the origin.

*The values are larger than, but quite close to (within 10% of), the values computed under the assumption that cities are homogeneous.

TABLE B-2

	$\hat{R}$(City)	SD
Boise	.181	.022
Eugene	.084	.016
Portland	.060	.009
Seattle	.079	.014
Spokane	.073	.019
Tacoma	.048	.012

$\hat{R}$(all cities) = .083

$\hat{R}$(city, service)			SD
Boise			
	full	.107	.028
	self	.208	.028
Seattle			
	full	.074	.021
	self	.084	.015
Spokane			
	full	.028	.014
	self	.097	.024
Tacoma			
	full	.035	.017
	self	.057	.017

We list (Table B-3) the differences in estimated switching rates $\hat{R}$(self service, city) - $\hat{R}$(full service, city) for all cities other than Portland and Eugene (no self service), and the ordinary 95% confidence intervals. These intervals should properly be interpreted at something like the 80% level since they are being considered simultaneously (and after data snooping!). There is weak evidence for a self-service versus full-service effect.

Residual Analysis

We examined normal plots of the differences $[\hat{R}(\text{cell}) \quad \hat{R}(\text{city})]/\sqrt{\hat{X}(\text{cell})}$ for each city. The plots revealed no overt departures from normality, although there was one clear outlier for Seattle, which corresponded to a cell with unknown price difference; its omission would change $\hat{R}$(Seattle) negligibly.

The residuals give no clear evidence for an association between positive residuals and self-service stations.

The Homogeneity Assumption:

We tried to check the homogeneity assumption once we had reached the conclusion that only city and service mattered by applying a test of homogeneity of the service stations within each city-service cell, i.e., we calculated

$$\sum \frac{[\hat{R}(s) - \hat{R}_H]^2}{\hat{X}(s)\ \hat{R}_H(1-R_H)} \quad ,$$

TABLE B-3

	$\hat{R}$(city, self service) - $\hat{R}$(city, full service)	SD
Boise	.101	.041
Seattle	.010	.025
Spokane	.069	.029
Tacoma	.011	.023

where the summation is carried out over all stations with the city-service status specified by H, and referred it to a χ^2 distribution with df = (# of stations with the appropriate status) - 1. It turned out that the χ^2 corresponding to full-service stations in all cities other than Boise and Eugene were significant at levels ranging from .1 to .005, while those corresponding to self-service stations were not significant. This may just reflect the greater number of full-service stations.

In view of the excellent agreement between the variance of $\hat{R}$ as estimated by (B) and as estimated under the homogeneity-of-cities assumption we doubt that this represents a practically as opposed to statistically significant departure from homogeneity.

In any case, in view of the low switching rates, a substantially larger survey with suitable stratification to ensure adequate representation in each cell would be required to make any further analysis.

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16. ABSTRACT

The incidence of switching from unleaded to leaded gasoline for catalytic converter equipped vehicles was observed in six (6) major metropolitan areas of Region X. The average rate was 6.9%, with a 95% confidence interval (5.7, 8.1) was documented.

17. KEY WORDS AND DOCUMENT ANALYSIS

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