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Contents

Mental Maps and the Refueling Behavior of Vehicle Drivers

DENNIS DINGEMANS, DANIEL SPERLING, AND RYUICHI KITAMURA

The spatial and temporal characteristics of refueling behavior are examined using survey data obtained from interviews with 309 local residents purchasing gasoline in Davis, California. Mental maps of roughly similar detail and accuracy are shown to be possessed by the major demographic and socioeconomic subgroups of the population studied. Most drivers could correctly identify only a small share of the least and most expensive gas outlets or diesel fuel options available to them. Stations at highly visible freeway exit locations were identified no more frequently than were stations in downtown or neighborhood locations. Expressed attitudes favored economically rational decisions in choices concerning trade-offs between extra travel and lower prices. This study has applicability for the design of a parsimonious network of subsidized refueling stations for alternative fuels such as alcohols, natural gas, or hydrogen.

This study is part of a long-range research program seeking to conceptualize and model the refueling decision of drivers for the purpose of designing an initial network of outlets offering alternative fuels. Since the establishment of that first, sparse spatial system will most likely require subsidy (or government intervention of some sort), an important public policy goal will be to select sites that become known rapidly to early adoptors of alternative fuel vehicles. The diffusion of new fuel vehicles will be accelerated if drivers can be made confident that the initial network will meet their refueling needs. Developing this more complete general understanding of the refueling decision process and refueling behavior will contribute to the lifting of perceptual barriers to the expansion of the nation's private transportation fuel options.

The spatial cognitions, or mental maps, of private vehicle drivers are investigated. The mental map of one individual is defined as that person's awareness of locational and product attributes of fuel outlets. Mental maps were studied to determine the degree to which drivers learn the full range of refueling options available to them in today's relatively unconstrained retail fuel environment. This study was limited to mental map knowledge of the fuel outlets close to the subject's residence, and only peak-hour refueling activity was examined. These limitations reflect the expectation that the most common use of the first alternative fuel vehicles will be for relatively regular commutes to work or for routine social and shopping travel.

Published academic research on petroleum marketing has focused on the supply side, with little attention paid to buyers' attitudes or the journey to refuel. Retailers of vehicle fuels have been found to have diverse location preferences and pricing strategies *(1–3)*. Some studies have examined allegations of oligopolistic behavior at the level of production and wholesale distribution during the early decades of gasoline retailing *(4, 5)*. A recent research report concluded that the dramatic drop in the number of gasoline outlets during the 1970s was a continuation of ongoing market forces, unrelated to charges of price-gouging or oligopoly *(6)*. The effects of rising prices and fuel shortages since the early 1970s on refueling behavior have received little attention *(7)*. The behaviorally oriented gasoline marketing studies by the geographer Claus are, unfortunately, of limited applicability to the present research because Claus adopts the implicit assumption that the typical consumer is a traveller or first-time visitor to the roadside retailing environment *(8)*.

This study uses techniques of environmental perception research that have been applied to the marketing of convenience goods *(9–11)*. These mental map studies show that a subject's "awareness space" and potential "action spaces" are strongly shaped by previous activities and length of residence in the study area. The quality of mental maps, when measured as the number of locations and attributes known by the respondent, has been found to vary with the demographic and socioeconomic characteristics of the respondents. Mental maps are a function of those summary characteristics because they are, in turn, associated with distinctive work, social, and shopping travel experiences *(12)*.

Four specific objectives guided the research design of the Davis study: *(a)* to specify turbulence in the environment of refueling choices faced by drivers, *(b)* to discern the learning rate and stability of refueling behaviors, *(c)* to reexamine recent findings that sociodemographic attributes have little predictive power for refueling behavior, and *(d)* to determine which kinds of fuel outlet locations are most easily cognized.

THE RESEARCH METHOD AND THE STUDY AREA

A survey of 309 gas customers was conducted during the first 10 days of April 1985 at 12 of the 15 petroleum retailers in Davis, California. Davis is a university town with 48,000 residents in its built-up area. It is a town representative of most of the nation's population because it is functionally enmeshed in the metropolitan economy of the Sacramento standard metropolitan statistical area (SMSA), which has its central city just 12 mi to the east. Because a large flood control channel separates it by 8 mi from the central city, Davis has an especially distinct local identity and a self-contained market for most convenience-level retail shopping. This lack of nearby competition and limited refueling options was felt to be a fortunate attraction for a study of mental map learning processes and refueling behavior.

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Respondents who were residents of Davis were asked 26 questions about their attitudes toward the choice of fuels, their decision to buy at the station they were patronizing, and their awareness of other refueling opportunities in Davis. The interviewers were three undergradates from University of California, Davis, who had been hired and trained for the survey. Typically, the survey was completed while the car's tank was being filled. This in situ method was selected instead of telephone or mail surveys because it ensured that subjects would have a fresh memory of the situation surrounding their choice of station. This method is similar to that used by Sperling and Kitamura in their 1984 surveys of 1,500 refueling drivers in several California urban areas *(13)*. The Davis survey questionnaire was designed to elicit information that would confirm and extend the results from the 1984 study.

The surveys were done during peak hours in the morning (7:00 to 9:30) and in the afternoon (4:00 to 6:00). Twelve of the fifteen service station operators in town agreed to permit a survey at their station. Interviews were conducted at a mix of morning and afternoon hours during at least 2 days at most stations. The survey sample consisted of selecting the next arriving patron after each previous interview was completed. Selection of the next arriving patron may introduce a systematic bias if the sampling rate decreases during peak periods, but this was not judged to be a problem in the Davis study because the stations are relatively small and the survey team could approach almost every patron at all times. Excellent cooperation was obtained from drivers and only about a dozen declined to participate.

The typical refueler reported the tank to be nearly empty (66 percent of drivers) or less than one-third full (93 percent). The typical interview subject claimed to drive 15,000 mi a year, and was driving a 1977 (7-year old) vehicle that was more likely to be an import (55 percent) than made domestically. Self-service users made up 86 percent of those surveyed, and 82 percent bought nonpremium fuel.

The sample population reflected the town's status as a university community of well-educated and professional persons. Just 28 percent were enrolled 1984–1985 students, although one-half of those surveyed worked or studied at the University of California, Davis. Full-time jobs were held by 62 percent. Younger people were overrepresented compared to the state as a whole: 67 percent were under age 35. Most were from small households with few or no children (69 percent of the sample) and just one adult (21 percent of the sample) or two adults (50 percent) present. The median household income category was solidly middle class at $20,000 to $30,000. Residential stability was notable, as 9 years was the average residence time in Davis, and only one-third had lived in town 3 years or less.

The refueling trip was generally reported to be part of a well-established and stable pattern. Some 60 percent reported that they regularly (often or always) stop at the station where they were interviewed, and the same number reported that they made the decision to stop there on the day of the survey out of habit. To get to their chosen station most reported that they did not have to go out of their way at all (41 percent) or, at most, less than two blocks (55 percent). Two-thirds knew the station well enough to agree that the station personnel were especially agreeable (fast, friendly, or reliable). Home was the typical origin of the refueling trip, and work was the most common destination, although just 29 percent of the trips were reported to be simple home-work or work-home trips. The number of special-purpose refueling trips was high; 10 percent said this trip was made exclusively for refueling and that they would return directly to their trip origin (home or work) after refueling. This was comparable to the findings of 7 percent special-purpose refueling trips reported by Sperling and Kitamura *(13)*.

Davis customers have a full range of the typical choices found in most towns, as five majors (four Shell, four Chevron, two Mobil, one Union, and one Exxon) and three independents sell fuel in town. Credit cards can be used at nearly all of the stations. One-third of the Davis stations offer a 4-cent discount when cash is used, a practice that is recent in origin and rapidly spreading nationwide. The geography of the town's gas stations is a good representation of the typical location pattern encountered by refueling drivers in most metropolitan area suburbs or free-standing small cities. The 15 stations in Davis fall into three recognizable locational types. Three are downtown stations, the last remnants of the trend that reduced the number of downtown Davis stations from its high of 10 in the era when most stations were located in the downtown area. Seven stations are freeway-access stations clustered along the town's two exits from I-80. The final five stations are neighborhood stations located on arterial streets east (two stations) and west (three stations) of downtown.

PREDICTABILITY AND TURBULENCE IN REFUELING OPTIONS

The characteristics of the local refueling network during the time of the survey and in the 6-month period before the survey are identified in this section. These data were essential benchmarks for assessing the accuracy of mental maps and reveal that refueling decisions during the survey were being made in a period of substantial turbulence with regard to the price of fuel.

Over a 6-month period before the surveys, a weekly record was made of the price and kinds of fuels offered by each station in town. The characteristics and prices of the 15 stations in Davis were the primary content of the mental maps of Davis's refueling drivers. Figure 1 shows the changing average weekly price before and after the weeks of the survey. This was a somewhat turbulent period as substantial price fluctuations, mirroring national trends, took place during the period when the subjects were expected to have formed or revised their mental maps of fuel availability and price. Prices were slowly rising and then stable during most of the fall. They had fallen sharply by early 1985. The trend was reversed and prices increased in late winter and early spring up to a peak slightly above the fall levels. The surveys were conducted during the steepest part of the upward price trend (Weeks 31 to 33 in Figure 1). This probably introduced some uncertainty in the minds of gasoline purchasers, even those with well-established refueling habits, exactly at the time of the survey. Davis drivers presumably tried to learn whether the rise in prices was universal or whether their regular station was changing its pricing policy compared to its nearby rivals.

Although prices changed considerably during the study period, the spatial surface of relative prices in Davis was stable.

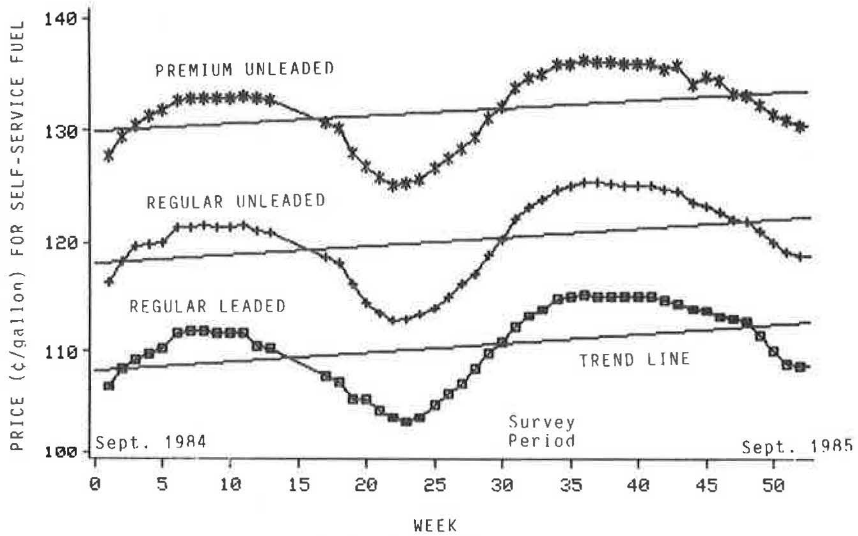

FIGURE 1 Weekly average fuel prices in Davis.

Most stations varied little in their price compared to the town average. Stations offered the same relative prices and the same kinds of gasolines throughout the year. Figure 2 and Figure 3 show the relative price stability of a low price and several moderate price stations. With a few exceptions, a fuel customer that exerted the effort to maintain perfect knowledge of the full range of prices would have about the same ability to make cost-minimizing choices as the driver who had studied the geography of price in the early fall of 1984 and stuck with an initial judgment about which station to patronize.

A final element complicating the typical consumer's effort to learn the geography of fuel price is indicated in Table 1. Davis drivers needed to learn two distinct maps of gasoline prices, one for self-service prices and another for full-service prices. This is shown in the correlation matrix that reveals that the various self-service and full-service prices are not strongly correlated at the station level. The stations that were lowest in price for self-service gasoline were different from the stations that offered the lowest price for full-service delivery of fuel. Three examples of this complicated pattern are the three downtown stations: they offered self-service fuel that was priced near or above the average but were by far the cheapest for full-service regular, unleaded, and premium fuels. The map of fuel prices was also not easy to identify by areal generalizations. The neighborhood stations and the freeway stations had a complicated pattern that was not easy for drivers to summarize, with one-half of the stations in each location charging well above the average price for full-service fuel but with the same or nearby stations charging low prices for self-service fuel.

MENTAL MAPS: AWARENESS OF REFUELING OPPORTUNITIES

Drivers' knowledge of fluctuating fuel prices and of the price and service attributes of fuel outlet locations were investigated. The primary indicator selected to measure mental map knowledge was the refueling driver's ability to identify correctly

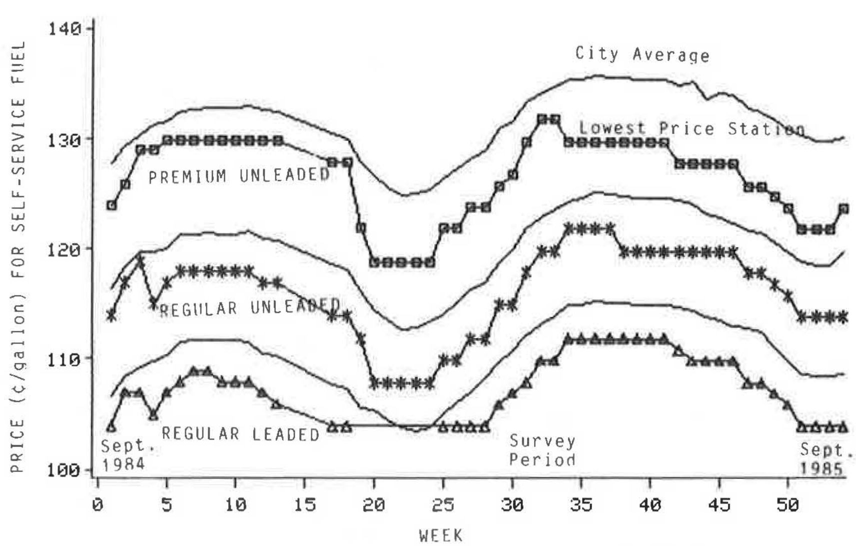

FIGURE 2 Fuel prices trends at the lowest price station in Davis.

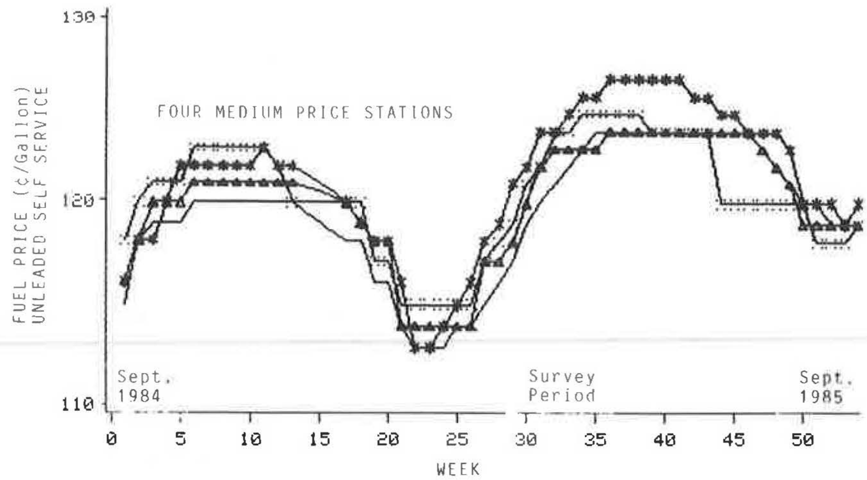

FIGURE 3 Fuel price trends at four medium price stations.

local stations and their characteristics. Drivers were not shown a list of stations or given the name of any station. To make this a test of spatial knowledge, responses were recorded only when it was clear that the specific Davis station location (and not the generic characteristic, such as "Chevron is most expensive") was known. Drivers were asked to name or locate the three stations in Davis that have the cheapest prices for fuel, the three that were the most expensive, and the three that offered diesel fuel.

These indicators have contrasting characteristics as measures of mental map spatial knowledge. The first indicator (number of stations correctly identified as cheapest) measures knowledge that is financially rewarding for most refuelers and is essential knowledge for "optimizing" their response with regard to price. The second measure (correct identification of the most expensive stations) is somewhat less useful to most refuelers, but is essential knowledge for the cost-conscious. It is assumed that many drivers will optimize efforts with regard to obtaining the lowest price, and a large number of drivers will be satisfied if they know they are paying less than the maximum price. It is assumed that only a very small number of drivers will be indifferent with regard to price. The relative price of gasoline at their favorite station is gratuitous knowledge for almost no one. The third question (the location of stations selling diesel) measured what must be gratuitous knowledge for most drivers. Therefore, this last variable is the best test of whether the average driver will learn the true availability of alternative fuels. Examined in concert and in combination with other attributes of the drivers, these measures reveal many important characteristics of the "learning curve" for spatial knowledge about refueling opportunities.

TABLE 1 STABILITY AND PREDICTABILITY IN FUELS PRICING

	Intrastation Correlations	
Type of Fuel	Unleaded Self-Serve	Unleaded Full-Serve
Unleaded self-serve	—[a]	0.57[b]
Unleaded full-serve	0.57[b]	—[a]
Leaded self-serve	0.96[b]	0.35[b]
Leaded full-serve	0.35[b]	0.98[b]
Premium, unleaded, self-serve	0.89[b]	0.68[b]
Premium, unleaded, full-serve	0.67[b]	0.85[b]

Source: 33-week survey of fuels prices at all (n=15) Davis stations.
[a]No data.
[b]Correlations significant at 0.01 level.

One general feature of the mental maps was found to correlate with the most basic propositions of learning theory: direct financial interest (utility) is an efficient motivator of learning. Refuelers were found to be most accurate in identifying cheap stations and to be least accurate in naming diesel stations. Table 2 reveals that one or more of the correct responses were given 69 percent of the time for cheap stations, 44 percent of the time for expensive stations, and just 22 percent of the time for diesel stations. Incorrect answers showed the opposite pattern but justify the same conclusion: those at least partially in error included 20 percent of the number of those naming a cheap station, 31 percent of those naming an expensive station, and 40 percent of those naming a diesel station. Not surprisingly, as the object of the mental map knowledge becomes of more immediate financial importance, subjects showed that they had gained better knowledge of it.

Several social and demographic independent variables were examined as possible correlates of mental map knowledge. The first of these was residential stability. The amount of time residents had lived in town was a significant predictor of respondents' abilities to identify refueling stations. In general, the number of stations correctly identified (as cheapest, most expensive, or diesel) rose with residential time (see Table 3). There were some instructive variations, however, in the length of residential time at which the clear learning curve leveled off. For identification of cheapest stations, about 18 months was the break point beyond which the score no longer rose consistently with residential time. This generalization relies on examination of more detailed data not given in Table 3. For the naming of expensive stations, scores no longer improved consistently after 60 months of residence. Knowledge of diesel stations rose gradually by age category until reaching its peak with those that lived in Davis 120 months or more. The ability to avoid errors in identifying these three categories was clearly associated with increasing residential time. The pattern for correct identifications suggests that drivers remember best the location

TABLE 2 KNOWLEDGE OF LOCAL STATION CHARACTERISTICS IN DAVIS

Question	Drivers with a Correct Response	Drivers with a Wrong Response	Mean Number Stations Correct	Mean Number Stations Wrong	Ratio of Wrong to Correct (%)
Locate three cheapest	212	42	1.12	0.15	13
Locate three most expensive	106	33	0.39	0.11	29
Locate three selling diesel	67	27	0.30	0.10	35

Source: April 1985 survey of 309 refueling residents in Davis.

of the cheapest stations but pay less attention to the geographical facts that would enable them to avoid the most expensive stations. Unsurprisingly, they learn slowly the gratuitous knowledge of where diesel fuel is available. Elements of this pattern reappear in the data on other socioeconomic indicators.

Gender was one of several demographic indicators not strongly associated with systematic variation in mental map knowledge (see Table 4). Males are better informed about the diesel stations but less aware of the low-cost stations. Females are somewhat better prepared than males to avoid the most expensive stations. They guessed wrongly less often than did males.

TABLE 3 MEAN NUMBER OF STATIONS IDENTIFIED BY LENGTH OF RESIDENCE IN DAVIS

	0–3 yr n=106	>3–10 yr n=111	>10+ yr n=90
Correct on three cheapest[a]	0.80	1.20	1.07
Correct on three most expensive	0.28	0.52	0.47
Correct on three diesel[a]	0.12	0.34	0.45
Wrong on three cheapest	0.16	0.14	0.14
Wrong on three most expensive	0.08	0.06	0.10
Wrong on three diesel	0.09	0.12	0.09

[a]Differences for this row significant at 0.05. (chi square using count data not shown).

The age of respondents was not linked to their familiarity with refueling opportunities (see Table 5). Again, this was surprising because length of residence, a good predictor, is correlated with age in the sample of relatively young drivers. The oldest one-third of the sample, age 35 or more, was little or no better than the youngest one-third, age 24 or less, in naming cheap, expensive, and diesel stations, or in avoiding wrong responses.

TABLE 4 MEAN NUMBER OF STATIONS IDENTIFIED BY GENDER

	Males n=146	Femals n=143
Correct on three cheapest	0.99	1.19
Correct on three most expensive	0.37	0.40
Correct on three diesel	0.34	0.24
Wrong on three cheapest[a]	0.18	0.09
Wrong on three most expensive	0.11	0.13
Wrong on three diesel	0.10	0.10

[a]Row differences significant at 0.05 (chi square for count data not shown).

TABLE 5 NUMBER OF STATIONS IDENTIFIED BY AGE OF REFUELER

	<25 yr n=95	25–35 yr n=100	>35 yr n=95
Correct on three cheapest	0.99	1.20	0.86
Correct on three most expensive	0.42	0.38	0.37
Correct on three diesel	0.28	0.27	0.34
Wrong on three cheapest	0.15	0.18	0.10
Wrong on three most expensive	0.10	0.10	0.16
Wrong on three diesel	0.16	0.07	0.06

Note: Differences across rows not significant at 0.05.

Another basic demographic measure, household size and composition, proved to have little predictive power (see Table 6). Householders with one or more children were not significantly different in their mental maps from those living in childless households. Drivers living alone and those sharing their household with one, two, or three, or more other adults had similar scores.

The household income of the sample drivers did vary somewhat with measures of ability to name inexpensive, expensive, and diesel refueling opportunities. There was a slight tendency for knowledge of expensive stations and diesel stations to rise with income levels (see Table 7). Lowest income respondents (the 24 percent of the sample with income declared to be less than $10,000) were close to the highest income respondents (the 16 percent with income over $50,000) in their average number of cheap stations named correctly (or incorrectly). When it came to naming expensive stations, the wealthiest group distinguished itself by doubling the score of the lowest income group. In knowledge of diesel stations the wealthiest group tripled the average score of the lowest income group. The increase in awareness of diesel fuel availability among the higher income groups might be a result of the prestige image of many diesel cars and an increased ability to buy one.

As might be expected, current students have lower levels of knowledge (see Table 8). This overall relationship is explained largely by the intervening variable of residential time in Davis. More interesting is the clear pattern whereby the relative level of students' knowledge increases as the direct financial benefit of that subject area increases. In knowledge of diesel stations, students only scored at 50 percent of nonstudents. In knowledge about the location of expensive stations, students do better: they score 68 percent of the nonstudent rate. In the most

TABLE 6 MEAN NUMBER OF STATIONS IDENTIFIED BY HOUSEHOLD SIZE

	0 Child n=193	1–1+ Child n=86	1 Adult n=63	2 Adults n=148	3–3+ Adults n=79
Correct on three cheapest	0.91	1.06	1.03	1.16	1.17
Correct on most expensive	0.36	0.47	0.30	0.41	0.42
Correct on three diesel	0.30	0.29	0.27	0.33	0.25
Wrong on three cheapest	0.14	0.15	0.11	0.12	0.20
Wrong on most expensive	0.10	0.14	0.05	0.09	0.16
Wrong on three diesel	0.09	0.20	0.03	0.09	0.16

Note: Row differences not significant for children or adults at 0.05 (chi square with count data not shown).

directly relevant knowledge regarding the cheapest stations, students perform at 82 percent of the nonstudent level. Students, with their overall poorer mental maps, were, nevertheless, no different than nonstudents in their willingness to guess and thus give wrong responses on these three questions.

Two additional social indicators were tested for their ability to predict the accuracy of mental maps. Employment status (those working full time, part time, or not at all) was neutral with regard to spatial knowledge of the type the survey tested. Self-identified trendsetters had slightly less knowledge than did those who were not innovators.

Finally, two situational variables were examined to determine if the type of trip, measured as named origin and destination (see Table 9), was associated with the level of mental map knowledge. Here there were only weak associations, but their direction is suggestive for further investigation. Interviewees on refueling trips to or from the workplace were less able to identify cheap, expensive, or diesel stations than were drivers on shopping, personal errand, social, or recreational trips. This finding is not just a result of the hurried commuter driver's unwillingness to take time for the survey, because drivers heading to or from work had average error scores similar to the noncommuting drivers.

In summary, the accuracy and extent of mental map knowledge was found to depend most clearly, but still only weakly, on the length of time residents had lived in Davis. Sociodemographic subgroups of the population were found not to vary consistently in the accuracy of their mental maps. Gender, age, income, and household size had been expected to be more strongly associated with greater levels of locally based activities and with greater knowledge of local retailing opportunities *(12)*. This surprising finding is consistent with the results of Kitamura and Sperling *(13,* and unpublished data) who found that refueling behavior is not efficiently predicted by the standard set of social characteristics that explain many other aspects of choice behavior in transportation. Additional, multidimensional analysis will be used in succeeding stages of this research project to examine the complex interactions of demographic, social, economic, and situational variables.

ARE FREEWAY RAMP SITES MORE WELL KNOWN?

The location of gasoline stations in downtown, neighborhood, and freeway sites was examined as an independent variable predicting the degree to which station features were accurately known. An initial hypothesis was that the characteristics of freeway ramp stations would be more widely and accurately known than in-town stations. This hypothesis was given some support in an earlier study by Sperling and Kitamura *(13)*. This was expected in the Davis case because the stations clustered around the town's two I-80 freeway exits are especially visible to dense traffic flows by local residents as they pass by or enter or leave town. The freeway clusters have the largest signs, the liveliest cross-street competition, and the widest variety of fuel type, fuel price, and service options. It was presumed that people have an image in their mind of diesel fuel outlets at truck service stops near freeway ramps.

A related hypothesis was that the town's neighborhood stations would be the least well known. The in-town stations include some sites that are hidden away or at peripheral locations. Two stations are on the far eastern side of town, not on any main route out of town. Two stations are in the far northeast corner. One downtown station is in a low-traffic corner near the intersection of two railroad lines. None of these are likely to be seen regularly on commuting or shopping trips by

TABLE 7 MEAN NUMBER OF STATIONS IDENTIFIED BY HOUSEHOLD INCOME

	0–9[a] n=65	10–19[a] n=57	20–29[a] n=52	30–49[a] n=50	50+[a] n=43
Correct on three cheapest	0.94	1.12	1.25	1.04	1.00
Correct on three most expensive	0.35	0.35	0.44	0.44	0.67
Correct on three diesel[b]	0.14	0.21	0.37	0.44	0.47
Wrong on three cheapest	0.15	0.14	0.10	0.10	0.20
Wrong on three most expensive	0.06	0.12	0.17	0.14	0.07
Wrong on three diesel	0.12	0.05	0.12	0.16	0.05

[a]In \$000s.
[b]Row differences significant at 0.05 (chi square with count data not shown).

TABLE 8 MEAN NUMBER OF STATIONS IDENTIFIED BY STUDENT STATUS

	Students n=87	Nonstudents n=217
Correct on three cheapest stations[a]	0.97	1.18
Correct on three most expensive	0.30	0.44
Correct on three diesel stations[a]	0.18	0.35
Wrong on three cheapest stations	0.15	0.15
Wrong on three most expensive	0.08	0.08
Wrong on three diesel stations	0.09	0.11

[a]Row differences significant at 0.05 (chi square with count data not shown).

residents that do not live on the same side of town. The motivation of these hypotheses was to address the question of whether a sparse, initial network of alternative fuel outlets should avoid neighborhood (or downtown) stations in favor of more easily cognized freeway ramp sites.

The evidence from the Davis survey does not provide strong support for the freeway ramp sitting strategy. None of the cheapest or most expensive stations located in neighborhoods were underrepresented in the mental maps of stations with those extreme qualities. In fact, Davis drivers had, on average, more accurate mental map knowledge about the six neighborhood stations than they did about the seven freeway stations. The features of the three downtown stations were less well known than were those of the suburban neighborhood stations. Table 10 reveals the average perception of a station's features in comparison with the 33-week data for each station. It is a crude measure of the error in mental map evaluations. The contrast is shown most clearly in estimations of the cheapest stations: the average measure of misperception is double for freeway stations compared to that of neighborhood stations.

These findings suggest that the reverse of the initial hypothesis may be the best guide for locating alternative fuel stations. The Davis experience supports a strategy of selecting an in-town station instead of a freeway exit station to ensure that the maximum number of local residents will be made aware of the availability of new fuel opportunities.

INCONGRUENT ATTITUDES AND BEHAVIORS

This section of the analysis examines the correlation between observed refueling behaviors and the expression of underlying attitudes toward the refueling decision. Attitudes were determined by asking the reasons for patronizing the selected stations. Questions addressed the willingness to travel extra distance to obtain price savings. The survey data show that Davis drivers profess to be more price sensitive than they really are. Many fail to drive a slight additional distance in order to obtain significant fuel cost savings. One explanation for this mismatch between attitudes and behavior is imperfect knowledge of alternative opportunities.

By several measures of direct behavior the Davis drivers are, in reality, relatively unconcerned about the price of fuel. When asked to identify the primary reason for selecting a particular station on that day only 17 percent chose price, while location was named by 45 percent and 38 percent named the quality of the gasoline or services. In their expression of greater concern for convenience than for price the Davis drivers are exhibiting attitudes and preferences similar to those found in industry surveys (Chevron Oil Company, unpublished data) and in the studies of other Northern California refuelers. Sperling and Kitamura *(13)* found in their earlier survey that 50 percent of drivers chose a station because of locational convenience, 34 percent because of price, and 17 percent because of some aspect of the station's service or product quality.

There is some evidence that the preference for a convenient location is motivated by an even more powerful attitude: a preference for predictability and regularity, especially for drivers during the morning rush-hour commute. Most (61 percent) of the Davis drivers bought fuel often or always from the same station, and most (57 percent) said that it was a habit to buy from that station. These figures from a small city with a relatively easily identified network of refueling options correlate closely with the unpublished results of the survey reported in Sperling and Kitamura *(13)* in which an unexpected stability of refueling choice patterns was reported for a wide variety of urban environments.

Even though just one-sixth of drivers ranked price as their major concern, the Davis drivers did express some economically rational attitudes and intentions that are somewhat at variance with their real-world behaviors. Drivers were asked if they would be willing to travel out of their way and an additional distance (0.5, 1, or 2 mi one way) to buy fuel that was cheaper per gallon by 3, 6, or 10 cents (for the same gas as they were buying). Figure 4 shows the willingness of drivers to trade-off extra travel for fuel price savings. Table 11 reveals the correlation between their attitudes and what might be called

TABLE 9 MEAN NUMBER OF STATIONS IDENTIFIED BY TRIP ORIGIN AND DESTINATION

	Origin			Destination		
	Home n=177	Work n=45	Other n=63	Home n=78	Work n=91	Other n=78
Correct on three cheapest	1.12	0.86	1.06	0.79[a]	1.13[a]	1.35[a]
Correct on three most expensive	0.40	0.42	0.44	0.31	0.34	0.67
Correct on three diesel	0.30	0.29	0.35	0.35	0.22	0.35
Wrong on three cheapest	0.14	0.18	0.25	0.15	0.12	0.16
Wrong on three most expensive	0.13	0.09	0.11	0.01[a]	0.19[a]	0.21[a]
Wrong on three diesel	0.13	0.09	0.08	0.13	0.09	0.09

[a]Row differences significant at 0.05 (chi square with count data not shown).

TABLE 10 PERCEIVED CHARACTERISTICS OF DOWNTOWN, NEIGHBORHOOD, AND FREEWAY STATIONS

Station	Location[a]	Perceived Cheapest[b]	Rank by Price[c]	Perceived Expensive[d]	Error 1[e]	Error 2[f]
4	D	8	6	13	2	7
5	D	5	7	11	2	4
	All D				2	5.5
1	N	10	9	7.5	1	2.5
2	N	11.5	13	14	1.5	1
3	N	3	3	6	0	3
7	N	1	2	3	1	1
8	N	11.5	12	7.5	0.5	4.5
	All N				0.8	2.4
9	F	2	1	2	1	1
10	F	13.5	14	12	0.5	2
11	F	4	5	9	1	4
12	F	13.5	10	10	3.5	0
13	F	6	8	4.5	2	3.5
14	F	9	11	4.5	2	6.5
15	F	7	4	1	3	3
	All F				1.7	2.9

[a]D = downtown, N = neighborhood, and F = freeway.
[b]Rank of frequency of citation as cheapest station (Rank 1 = most frequently cited).
[c]Rank of average price for unleaded self-serve fuel (Rank 1 = lowest).
[d]Rank of frequency of citation as most expensive station (Rank 14 = most frequently cited).
[e]The difference in ranks between perceived cheapness and actual price.
[f]The difference in ranks between perceived most expensive and actual price.

economic rationality. The majority claim to be unwilling to travel the extra distance unless their extra time expenditure is compensated at a rate of more than $6/hr. This monetary value was obtained first by subtracting the cost of extra travel (round trip, at 20 cents/mi) from the fuel savings in a 12 gal fill-up and then dividing that figure over the time required for the extra round-trip travel (at an average city travel speed of 24 mi/hr). For $15/hr savings, three-quarters of the Davis drivers would expend the extra time and distance. The option of driving an extra 0.5 mi to save 10 cents/gal seems reasonable to 86 percent of the drivers and yielded a net savings rate of $29/hr.

The actual behavior of the Davis drivers was somewhat at variance with these expressed attitudes. Many of those surveyed were, in practice, continuing to shop at their habitual or most convenient station, even though this would result in increased costs. Most of those at the downtown Stations 4 and 5 were refueling at a cost of 3 or 4 cents/gal higher than they would pay just 0.5 mi away (at Station 7 where unleaded self-serve was $1.179 the week of the survey). For a 12-gal fill-up the savings earned by driving to the cheaper station would equal almost $9/hr. A survey was conducted on dozens of refuelers who were paying a 5- or 7-cent/gal premium by refueling at the far northeast Stations 1 and 2 instead of driving the extra mile to the cheaper Station 3. These drivers were failing to take an action that would have rewarded them at a rate of between $9 and $17/hr.

Imperfect knowledge on the part of many drivers helps explain the incongruence between attitudes and behavior. The 53 drivers that said price was their main reason for selecting a station had by far the best mental maps. These avowedly price-conscious drivers could name an average of 1.6 (out of a possible 3) of the town's cheapest stations. Those 253 drivers that were more concerned with convenience and quality were able to name an average of just 1.0 of the cheaper stations. This superior knowledge was duplicated, but at a lower level, when expensive stations were being named (0.58 versus 0.36 correct per capita). The especially price-conscious drivers were no better than average (0.29 correct) in naming the town's diesel stations, demonstrating again that the drivers had well-developed mental maps only for those subjects that could immediately save them money.

A final indicator shows additional evidence of a correlation between price-conscious attitudes and actual refueling behavior. All drivers were asked to name the street on which

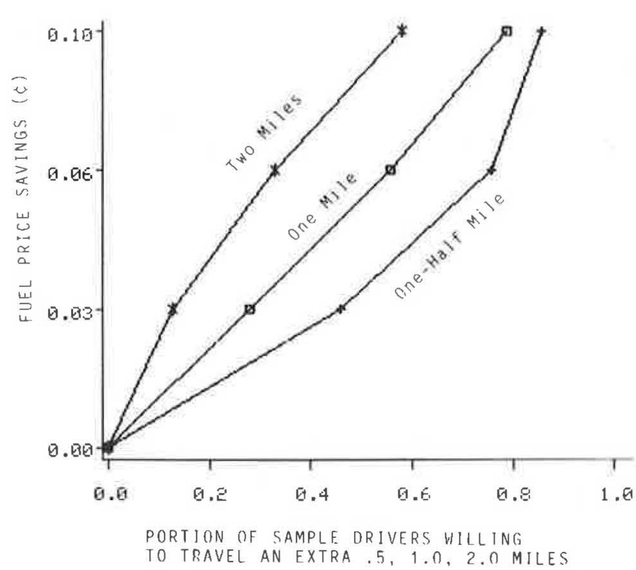

FIGURE 4 Attitudes toward extra travel for fuel price savings.

TABLE 11 IMPUTED VALUE OF TRAVEL FOR FUEL PRICE SAVINGS PER HOUR

	0.5 mi		1 mi		2 mi	
Price Savings ($)	Savings ($)[a]	Driver Willingness (%)[b]	Savings ($)[a]	Driver Willingness (%)[b]	Savings ($)[a]	Driver Willingness (%)[b]
0.03	8.84	46	4.72	28	1.36	13
0.06	17.48	76	9.04	56	3.52	33
0.10	29.00	86	14.80	79	6.40	58

[a]Valuation of refueling driver's time ($/hr), computed as total savings from lower gas price (12 gal fill-up) minus automobile cost ($0.20/mi) for extra 1-, 2-, and 4-mi round-trip travel to and from cheaper station. Estimated average city travel speed of 24 mi/hr.
[b]Refueling drivers were asked, if they knew of a station located 0.5, 1, or 2 mi, respectively, out of their way that sold the same gas at a lower price, would they go there regularly if it were cheaper by 3, 6, or 10 cents, respectively?

they lived and the nearest cross street, thereby preserving the required confidentiality while giving the near-exact home location. Based on this information the residence of each individual in the Davis survey was mapped and compared to the location of the refueling site. An average distance between home and refueling was computed as a simple estimate of each station's market area. The most expensive stations were found to have smaller average local market areas than the less expensive stations. The three lowest cost stations have market areas that are much larger than their adjacent competitors. The main implication from these market-area patterns is that Davis residents do exhibit some price-conscious behaviors that are at least partially congruent with their expressed attitudes about willingness to travel for price savings. However, Davis residents are far from being price optimizers. Many have habits of patronage at expensive but more convenient stations, and over 80 percent rank location and quality as more important than price in selecting their regular station.

CONCLUSIONS

Most refueling choices in Davis were found to involve routine behavior and habitual patronage of a regular station. Judged by their choice of a station on the day of the survey, many Davis residents seemed to value a convenient location more than price savings. Locational convenience was especially important for the surprisingly high 10 percent of refueling trips that were single-purpose trips for refueling alone. This pattern of refueling close to home or work is expected to be found elsewhere, even in larger metropolitan areas and more complex situations with more refueling options.

The Davis findings suggest that age, sex, income, household size, and student status are not important predictors of refueling choices. Familiarity with the local area, measured by the length of local residence, is a more important variable for explaining refueling during home-based, peak-hour trips. More generally, refueling choices are the result of a learning process whereby drivers can identify the map of local opportunities. Mental map knowledge of refueling opportunities in Davis was found to vary with the driver's economic motivation, with learning processes proceeding more slowly when there are few prospects for direct economic reward from the knowledge. Refueling stations in Davis have a stable price structure that permits the establishment of stable refueling patterns and facilitates the establishment of accurate mental map knowledge of refueling options. This pattern of relative price stability in competition is expected to be found for most metropolitan areas.

These findings have implications for the design of an initial network of outlets for alternative fuels. Few of the Davis drivers who were not in the income cohort that is most likely to buy a diesel car could identify the freeway ramp locations where diesel fuel was available. In a parallel situation, few ordinary drivers could be expected to learn of the availability of an alternative fuel in Davis unless they had already begun to consider the possiblity of buying an alternative fuel vehicle. Local information dissemination programs might be needed to make all potential purchasers of a new fuels vehicle aware of the local availability of that new fuel. In locating the first few outlets for new fuels, decision makers should be most aware of the great premium placed on locational convenience.

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A Functional Form Analysis of the Short-Run Demand for Travel and Gasoline by One-Vehicle Households

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The short-run elasticity of vehicle travel and gasoline demand is analyzed using gasoline purchase diary data for households in the United States owning one vehicle. A Box-Cox method (iterative ordinary least squares) is used to determine best functional forms for each of four income quartiles in the sample. Transformation parameters for all income groups are found to be close to 0.4. Thus, price elasticity increases with increasing fuel prices. Elasticity estimates at the mean for the three upper quartiles are –0.6, and that for the lowest quartile is approximately –0.5.

How the short-run price elasticity of gasoline demand varies with income determines how severely price increases, whether as a result of shortages or other causes, will affect consumers in different income groups in the short run. This knowledge is important in formulating strategies for possible petroleum shortages, as well as understanding the impacts of fuel taxes. Despite the very large number of econometric studies of gasoline demand that have appeared over the last 15 years *(1, 2)*, very little is known about how price elasticities vary across income groups in the United States. Dahl *(3)* examined the variability of aggregate gasoline demand elasticities over time and across countries, as did Wheaton *(4)*. Their results showed no great differences in price elasticities across countries with widely differing average incomes. However, these studies did not use individual household data, and it is not possible to extend their results for whole countries to apply them to individual households in the United States. Although household survey data have been used in some studies *(5–7)*, the question of the variability of elasticities across income groups has not been addressed.

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The stability of the price elasticity of gasoline demand across income groups is studied using techniques that simultaneously estimate the appropriate functional form. U.S. studies of the functional form of aggregate gasoline demand functions using the Box-Cox method have suggested that the double-log model is appropriate *(2, 8)*. A New Zealand study revealed that results varied depending on whether monthly, quarterly, or annual data were used *(9)*. The analyses are extended in this paper by using disaggregate household data, and equations for income groups are estimated. The data is derived from a gasoline purchase diary survey conducted between April 1978 and March 1981 *(10)*. In order to simplify the analysis, only households owning one vehicle were included in this study. Future work will extend the analysis to multivehicle households.

The derivation of a gasoline demand equation from the household production theory of consumer demand is the subject of the next section; the data used in estimating the demand functions is briefly discussed in the third section; the Box-Cox transformation technique is the subject of the fourth section; estimation results are presented and discussed in the fifth section; and a conclusion follows in the sixth section.

THEORY

Household demand for gasoline is derived primarily from the demand for highway vehicle travel. The economic theory of household production *(11, 12)* provides an appropriate theory from which to derive models of travel *(13, 14)*, and gasoline demand. Households purchase the necessary inputs for the production of travel (vehicles, gasoline, maintenance, parts) and supply their own labor time to produce the quantity of travel desired. The crucial aspect of household production theory, as opposed to classical demand theory, is that it recognizes the central role of the technology of household production in determining demand. As will be shown below, the key factor in the technology of production that affects gasoline demand is the technical efficiency of the vehicle stock (e.g., miles per gallon). Especially in the short run, when characteristics of the vehicle stock are fixed, fuel economy of the vehicle stock is a critical explanatory variable.

Suppose that the household has the following utility function, U, which is weakly separable in vehicle travel, T, and a composite good, z, then

$$U = U(z, T) \tag{1}$$

This does not mean to say that the household derives utility directly from travel, but rather that utility is some weakly separable function of travel. The assumption of weak separability is not necessary to the final estimation of demand equations, but is used here to simplify the exposition. The household's economic problem is to maximize U, subject to constraints on income and leisure time available for producing travel. Following Michael and Becker *(12)* these are collapsed into a single constraint on full income:

$$I = wL - pz - C = 0 \tag{2}$$

where I is monetary income, w is the household's valuation of leisure time L, time not spent in producing monetary income, p is the price index of z, and C is the cost function for producing travel.

The travel cost function is of particular interest because it embodies the technology for producing travel:

$$C = [(P_g/\text{mpg}) + v + (w/\text{mph})]T + rA \tag{3}$$

The quantity in parentheses consists of the variable costs of travel: the gasoline cost per mile [price divided by miles per gallon (mpg)], other variable costs, v, (e.g., maintenance, lubricants, parts, insurance, etc.), and the time cost [the value of leisure time divided by average speed in miles per hour (mph)]. The final term represents the annualized vehicle cost, and is given by the asset price times a constant that is a function of the household's time discount rate (or its effective interest rate for capital). The technology of energy consumption enters through the determination of the fuel cost per mile.

The household's optimization problem can be written using a LaGrange multiplier:

$$\begin{aligned}\text{Max } U^* = U(z, T) - m\,\{&(I + wL - pz)\\ &- [(p_g/\text{mpg} + v + w/\text{mph})\,T + rA]\}\end{aligned} \tag{4}$$

The first order conditions for optimization are

$$\begin{aligned}\partial U^*/\partial T &= U_T + m\,(p_g/\text{mpg} + v + w/\text{mph}) = 0\\ \partial U^*/\partial z &= U_z + mp = 0\\ \partial U^*/\partial z &= (I + wL - pz)\\ &\quad + [(p_g/\text{mpg} + v + w/\text{mph})\,T + rA] = 0\end{aligned} \tag{5}$$

From these the expected result that the ratio of marginal utilities of travel and the composite good are equal to the ratio of their marginal costs is derived:

$$U_T/U_z = [(p_g/\text{mpg}) + v + w/\text{mph}]/P \tag{6}$$

In order to better illustrate how household demand functions for gasoline can be derived from this problem a particular utility function in Equation 4 can be substituted and the demand function for gasoline solved. This is done for the purpose of illustrating certain properties of all demand functions for vehicle travel. In fact, the functional form of U is unknown. In the estimation section below, the Box-Cox technique will be used to identify from a class of functional forms the one that best fits the data. Suppose that the utility function is additive in the logarithms of its argument [such a form is also separable, as assumed earlier *(16)*]: $U = a\ln(z) + b\ln(T) + c$. The first two equations of the first order conditions now become

$$\begin{aligned}\partial U^*/\partial T &= (b/T) + m(p_g/\text{mpg} + v + w/\text{mph})\\ \partial U^*/\partial z &= (a/z) + mp\end{aligned} \tag{7}$$

Substituting $m = -(a/pz)$ into the first condition gives $0 = b/T - (a/pz)\,(p_g/\text{mpg} + v + w/\text{mph})$. Then, solving the third condition (the budget constraint) for z, representing all monetary variables indexed to (divided by) the price of z with a prime(′), and substituting for z in the equation above gives

$$\begin{aligned}T = [&b(I' + w'L) - (p_g'/mpg + v' + w'/\text{mph})\,T - rA']\\ &\div [a(p'_g/\text{mpg} + v' + v'/\text{mph})]\end{aligned} \tag{8}$$

What remains is to solve for the demand for gasoline, instead of the demand for travel. A particularly simple way to represent the the household production function for travel is as a fixed input production function. That is, constant proportions of each input must be supplied *(17)*:

$$T + min\,(g^*\text{mpg},\ h^*\text{mph},\ n^*veh\ , \ldots) \tag{9}$$

where the first three inputs represent gasoline, time spent driving, and vehicle stock. At least in a short-run situation, a very good argument can be made that motor fuel is the only significant variable input to vehicle travel. Therefore, short of a breakdown, maintenance can be considered an annual cost and capitalized along with the cost of vehicle ownership. In any case, gasoline is always a limiting factor so that

$$T = min(g^*\text{mpg}\ , \ldots) = g^*\text{mpg} \tag{10}$$

is always true in the short run.

Substituting this travel production function into Equation 8 completes the derivation of the household demand function. The resulting function is arbitrary in that a particular utility function was arbitrarily chosen, yet it illustrates many important features of any valid gasoline demand equation:

$$g = 1/[1 + (a/b)] \cdot 1/\text{mpg} \cdot (I' + w'L - rA') \div (p'_g/\text{mpg} + v' + w'/\text{mph}) \qquad (11)$$

First, gasoline demand is a function of household income and the value of household time. As income increases, demand for gasoline will increase ($a, b > 0$ is implicitly assumed). As the value of household leisure time, w, increases, it affects gasoline demand in two opposing ways. Directly as the value of time increases, it increases full household income, which tends to increase the demand for gasoline. On the other hand it also increases the cost of household labor used to produce travel, which tends to decrease the demand for gasoline. Fuel economy has similar opposing effects. If higher fuel economy did not reduce the cost of travel, then an increase in miles per gallon would result in a proportional decrease in the demand for gasoline. Increased miles per gallon, however, also reduces the variable cost of travel, thereby increasing the demand for gasoline, because demand is inversely related to the total variable costs of travel.

The price elasticity derived from Equation 11 is not constant but depends on price, miles per gallon, the time cost of travel, and therefore on the wage rate. Although the particular form of the elasticity is peculiar to this example (Equation 12), it does illustrate that price elasticities are generally not constant.

$$\varepsilon_p = -\{1 + [(v' + w'/\text{mph})^* \text{mpg}]/p\}^{-1} \qquad (12)$$

This simple demand equation reveals a great deal about household gasoline demand and provides useful guidance about how to structure an equation that can be calibrated using actual consumption data. However, there are several important issues that still remain to be addressed. First, a particularly simple functional form was chosen for purposes of exposition. In estimation, allow for the possibility that other mathematical formulations better fit the data. This is taken up in the fourth section. Second, allow for the possibility that even in the short run the adjustment process may be dynamic. Because monthly data will be used to estimate the model, this is equivalent to saying that full, short-run adjustment occurs within a month. There is some empirical support for this assumption *(18)*, yet it would be an improvement to test for its validity.

Finally, there is the problem of including other relevant household characteristics in the demand equation. Factors such as the number of licensed drivers, the spatial environment in which the household lives *(19)*, and the availability of alternative transportation modes are clearly relevant. Because interest centers on the price elasticity of demand, these aforementioned influences need to be controlled to the greatest extent possible or removed. This is achieved by "centering" each household's data about the household mean and is described in the fourth section.

DATA

The source of the data used in this study is the National Family Opinion Poll (NFO) Gasoline Diary Panel survey, as modified by the Energy and Environmental Analysis (EEA), Inc. *(10)*. The original Gasoline Diary Panel consists of approximately 734,000 fuel purchase records completed for more than 15,000 vehicles over a 36-month period from April 1978 to March 1981. Each respondent entered data on each fuel purchase for every vehicle owned. The data included fuel type, odometer reading, gallons purchased, cost of purchase, and price paid per gallon. In addition, household demographic and economic data were recorded for each household at the beginning of its participation in the survey.

These individual purchase records were collapsed by EEA into a monthly summary data file about one-fifth the size of the original data base. In cases where purchases straddled 2 months, mileage and fuel consumption were allocated proportional to time. From this data base all those households owning only one vehicle were selected. This left a total of 3,777 households with 46,256 total monthly observations. This sample was subdivided into rough quartiles: *(a)* under \$8,000/year, *(b)* \$8,000 to \$12,000/year, *(c)* \$13,000 to \$19,000/year, and *(d)* over \$19,000/year. Each quartile contained roughly 1,000 households and 10,000 monthly observations. In each quartile 5 to 10 percent of the observations were either missing or unusable for some other reason.

Summary data for the income quartiles show a clear relationship between income and vehicle travel, as well as expenditures on fuel. Not only does the highest income quartile travel about 250 mi per month more than the lowest, but they also pay about 10 percent more for the fuel they buy (Table 1). Interestingly, there is very little variation across income groups in average miles per gallon (total miles per total gallons). Fuel prices are deflated to 1967 dollars using the consumer price index for urban consumers.

TABLE 1 SUMMARY STATISTICS FOR INCOME QUARTILES

Quartile	N	Mean Monthly Travel (mi)	Mean Fuel Price[a] (\$/gal)	Mean (mpg)	Mean Fuel Expenditures[a] (\$/gal)
Lowest	10,195	706	0.405	17.56	16
Low-mid	12,810	828	0.419	17.40	20
High-mid	10,496	934	0.420	17.66	22
High	9,674	964	0.440	17.56	24

[a]For 1967.

An important fact about the NFO survey data is that it is a representative panel survey, not a statistically valid random sample. Furthermore, it should be kept in mind that data for single-vehicle households only were used in this study.

ESTIMATION

In order to estimate demand equation parameters, a specific functional form must be chosen. Choice of functional form, however, can affect both the point estimates of price elasticity and how those estimates may vary as a function of price and quantity consumed. As a result it is desirable to use a method that allows functional form and parameter estimates to be inferred from the data. The most generally accepted and widely used technique for inferring functional form is by Box and Cox *(20)*. The Box-Cox approach allows generalized linear models of the form

$$g^{(\lambda_1)} = b_0 + b_{1}x_1^{(\lambda_2)} + \ldots + b_{k}x_k^{(\lambda_{k+1})} + e \qquad (13)$$

where the x_i's are explanatory variables, e is a random error term, and the b_i's are parameters to be estimated. The Box-Cox power transformation is defined as

$$g^{(\lambda)} = \begin{cases} (g^{\lambda} - 1)/\lambda & \lambda \neq 0 \\ ln(g) & \lambda = 0 \end{cases} \qquad (14)$$

The functional form of the equation is dictated by the λ_i's, which are estimated at the same time as the b_i's. Spitzer *(21)* describes four equivalent methods for estimating the parameters of a Box-Cox model. The method used here is iterative ordinary least squares (IOLS) using the scaling trick proposed by Zarembka *(22)*. By multiplying Equation 13 through by the geometric mean of observations on the dependent variable raised to the $-\lambda$, $\dot{g}^{-\lambda}$, the $R2$ of the scaled regression can be used to determine the value of λ. Actually, the independent variables need not be scaled by $\dot{g}^{-\lambda}$, provided it is recognized that the estimated b_i's will be scaled accordingly:

$$b_i^* = \dot{g}^{-\lambda} g_i \qquad (15)$$

The IOLS method is so called because regressions are iteratively performed using different values of λ_i's until the λ_i's providing the highest R^2 are found to the desired degree of accuracy.

In addition to the cost per mile (cpm) of motor fuel, a number of household and vehicle-specific variables might be expected to be included in Equation 13 as explanatory variables. Factors such as income, number of drivers, location of the household, availability of transit, population density, and others are candidates. The survey contains data for some of these but not for others. In addition, from Equation 10 the entire right-hand side of Equation 13 should be divided by miles per gallon.

To avoid many of the complications described, two tricks were used. First, monthly gasoline consumption was multiplied by average miles per gallon for the household and month, so that the dependent variable became monthly travel (in fact, miles per gallon in the survey were calculated as travel divided by fuel consumption, so that this is identical.) Second, after scaling and transformation, the data were centered by subtracting the household mean from each household's observation. This trick allows all household-specific variables that are constant over time—this includes income because monthly income was not recorded—to be dropped from the equation. It also eliminates the intercept term; in effect, each household has its own, unestimated intercept. The only variable remaining on the right-hand side is fuel cost per mile. It is possible that non-household-specific, time-dependent variables should be included in the regression, such as seasonal dummy variables or national economic trend variables. No attempt was made, however, to test such hypotheses in this analysis.

The final estimating form of the regression equation is therefore

$$g^{*(\lambda)} = b^{*}(\text{price/mpg})^{(\lambda)} \qquad (16)$$

Although the scaling and centering considerably simplify the regression equation to be estimated, they pose significant data processing burdens in sorting, calculating means, and transforming thousands of data observations. In order to reduce the number of iterations and hold down the cost of the analysis, only a single transformation parameter was estimated, λ. The 1982 PROC REG procedure of the SAS Institute was used throughout.

RESULTS

Estimation of the travel demand equations produced remarkably consistent results across income quartiles. Three of the four independently estimated IOLS solutions resulted in values of λ very close to 0.4. Only the lowest income quartile differed. Its transformation parameter was closer to 0.3, but the R^2 function is very flat in the region between 0.2 and 0.4 (Figure 1). It appears that the functional form of the relationship between vehicle travel and fuel cost per mile, and therefore, fuel use and fuel cost per mile, is very similar for all income groups. The low values of R^2 seen in Figure 1 are typical of disaggregate data.

Whereas previous studies using aggregate data have found that the logarithmic transformation ($\lambda = 0$) fits the data base *(2, 8)*, these results based on disaggregate data indicate that the constant elasticity formulation does not fit the data best. It can be shown that the cost-per-mile elasticity of travel (and gasoline) demand in the simple Box-Cox model is given by:

$$e = b_1 \text{cpm}/[\lambda(b_0 + b_1 \text{cpm}^{(\lambda)}) + 1] \qquad (17)$$

The elasticity of demand therefore depends on the price of fuel, miles per gallon, and the household intercept, which reflects the level of travel by the household. For reasonable values of the coefficients, elasticity will increase as price increases.

To compute elasticities, an intercept term must be computed because none was estimated. Rather than compute intercepts for each household, one intercept for each income group was

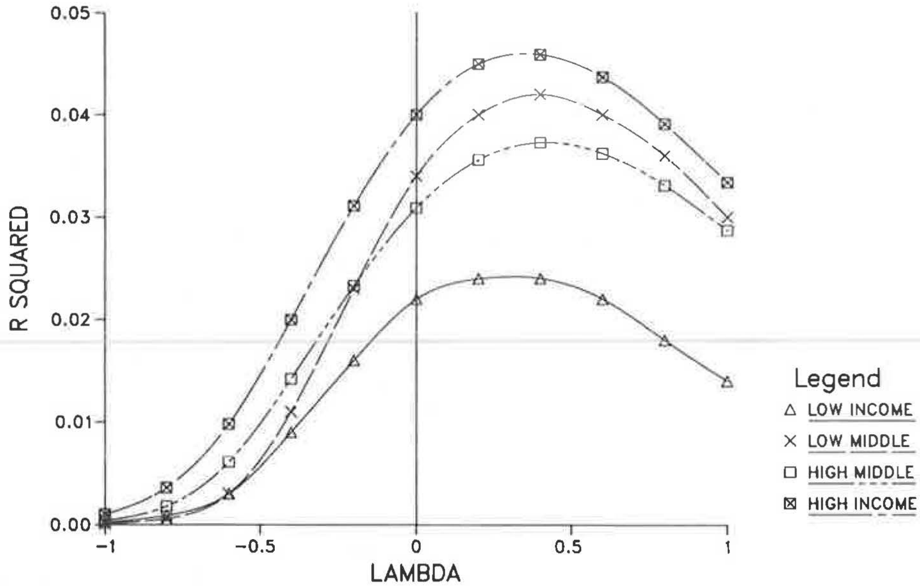

FIGURE 1 Dependency of model fit (R^2) on the Box-Cox transformation parameter (λ).

calculated using mean values (of the uncentered, transformed variables) for each group, and the relationships:

$$b_0^* = (\overline{T}/\dot{T})^{(\lambda)} - b_1^*(\text{cpm})^{(\lambda)}$$

$$b_1 = \dot{T}^{\lambda} b_1^*$$

$$b_0 = \dot{T}^{\lambda} b_0^* + \dot{T}^{(\lambda)} \tag{18}$$

The data used to make these calculations, together with the estimated model coefficients are given in Table 2. The suffix bar in a variable name indicates an arithmetic mean, while a dot indicates a geometric mean. Costs per mile are in 1967 cents per gallon.

Both the b_1 coefficients and, to a lesser extent, the estimated elasticities increase in magnitude with increasing income. The pattern of increase is quite interesting. There is a substantial jump in elasticity from the lowest to the low-middle income group, but elasticities remain essentially constant thereafter. Apparently, price responsiveness of gasoline demand is essentially the same for middle and upper income groups, and slightly less elastic for the lowest income group. The computer elasticities range from about –0.5 to –0.6, larger than the range of –0.1 to –0.3 typically found in the literature for short-run gasoline demand *(23)*. In Table 3 elasticities from the double log model are compared with those from the optimal Box-Cox transformation: the differences are small and the pattern is the same. Using the same data set, Greene and Hu *(5)* estimated a short-run fuel price elasticity of vehicle travel for all income groups combined of –0.3. They included seasonal factors in the regressions. It is likely that the exclusion of such time-dependent factors in this analysis has inflated the cost-per-mile coefficients.

TABLE 2 TRAVEL ELASTICITY ESTIMATES FOR HOUSEHOLDS BY INCOME GROUP

	Income Groups				
	Lower	First	Second	Third	Fourth
λ	0.2	0.4	0.4	0.4	0.4
TBAR (λ)	0.0697	0.1379	0.1143	0.1024	0.1092
CPMBAR (λ)	0.79	0.89	0.93	0.93	0.97
CPMBAR	2.29	2.29	2.35	2.34	2.41
LOG(TDOT)	6.43	6.42	6.61	6.74	6.76
TDOT	620.17	620.17	742.48	845.56	862.64
b1*	–0.419	–0.357	–0.437	–0.431	–0.439
b1	–1.52	–4.67	6.15	–6.39	–6.56
b0*	0.40	0.46	0.52	0.50	0.54
b0	14.54	36.20	40.00	42.01	42.84
Mean elasticity	–0.49	–0.48	–0.60	–0.59	–0.61
Predicted annual travel	7,616	8,248	9,599	10,838	11,116

TABLE 3 COMPARISON OF FUEL COST ESTIMATES

	Income Quartiles			
	First	Second	Third	Fourth
Double logarithmic	−0.49	−0.56	−0.55	−0.61
$\lambda = 0.4$	−0.48	−0.60[a]	−0.59	−0.60
Greene and Hu		−0.29		

[a]For all.

CONCLUSIONS

This preliminary analysis of the short-run price responsiveness of household motor fuel demand suggests that demand functions vary little across income groups, either in functional form or price elasticity. For the upper three income quartiles, there is nearly complete agreement. Transformation parameters are nearly identically equal to 0.4, and the estimated elasticities at the mean are all −0.6. Only the lowest income quartile differs, and still the differences are slight. Lambda is approximately 0.3, and the price elasticity is somewhat lower, about −0.5. The differences between the lowest and highest income quartiles suggest that the lowest income quartile should be examined more closely to see whether more extreme differences exist within this quartile. The similarity of results for the upper quartiles suggests that it may be possible to aggregate households in these groups for purposes of studying price elasticities.

It is likely that the price elasticity estimates obtained here are inflated by the failure to include other time-dependent factors such as economic trends and seasonality. Future work should address this issue. The functional forms studied here allow one transformation parameter only. The usefulness of additional transformation parameters should be explored. Finally, this study has used data from households owning one vehicle only. This enabled very simple models to be formulated. Future work must address the majority of households owning two or more vehicles.

ACKNOWLEDGMENT

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An Assessment Methodology for Alternative Fuels Technologies

P. HALLETT AND G. HAMILTON

Through its federal research and development (R&D) policy, the government of Canada has committed itself to active participation in R&D. In the field of road energy technology R&D, the federal government is one of the several players in addition to provincial governments, universities, the private sector, and others. Because of its legislative mandate Transport Canada bears significant responsibility in the area of alternative field technical R&D. Therefore a framework that facilitates coordination of federal expenditures with others and ensures the identification of gaps in R&D so that resources can be focussed on promising research directions was required. Criteria for assessment includes the degree of support for national energy objectives, Canadian commercialization potential, contribution to a more cost-effective transportation system and, from a federal perspective, the contribution to departmental mission objectives. The technology assessments form essential components of a strategic road energy R&D plan aimed at identifying promising research directions and providing a technological success indicator for guiding the allocation of federal energy R&D resources in transportation. Program areas in which federal-provincial joint efforts should be strengthened or initiated in support of national transportation system energy efficiency are highlighted in the paper. The technology assessment exercise, on which this paper is based, is a first step in developing a plan and consensus on strategy for pursuing the most promising road energy R&D within Transport Canada, within the federal government, and between the federal government and nonfederal interests.

Research and development (R&D) has always been an integral part of Canadian industry and government activities. A government review in 1978 of the state of R&D in Cánada, however, revealed that commitment to R&D in Canada was low overall compared to other industrialized nations, and that there was a growing imbalance between the government and industry sectors, both as a source of funds and as performers of R&D.

Of the initiatives that followed, the two most significant were the 1980 National Energy Program (NEP) that established specific targets for energy self-sufficiency, and the 1981 Ministry of State for Science and Technology (MOSST) Federal R&D Policy that identified transportation, energy, space, communications and oceans as the five areas for national R&D concentration.

The nature of the role chosen by the federal government (as promoter and financier) of R&D and its representative departments, as a result of these initiatives, necessitated the requirement for

1. A mechanism to ensure coordination of federal R&D activities and financial support, and
2. Development of an overall strategic plan aimed at identifying promising research directions characterized by a high return on investment.

To ensure coordination of energy R&D within the federal government, the Interdepartmental Panel for Energy Research and Development (PERD) was established. Federal R&D is categorized into six task areas: conservation (including transportation and demand programs); oil sands or heavy oil, and coal; nuclear energy; renewable energy; new liquid fuels; and conventional energy resources.

The latter requirement, that of developing a strategic plan and methodology to facilitate guiding the allocation of federal energy R&D resources in these areas, has been left to panel members, representatives of departments whose mandates encompass one or more of the aforementioned six areas. Of the six task areas, alternative fuels technology was chosen as the area to illustrate the development of a methodology; road transport was used as the specific example.

Road energy R&D is being undertaken or supported by a wide variety of parties in Canada (Figure 1). Various federal and provincial government departments and agencies, municipalities, universities, and private industry are active in this area.

Transport Canada has a clear mandate, as a result of legislation such as the Road and Motor Vehicle Safety Act, to be responsible for new vehicle safety, emissions, and fuel economy. To ensure that its responsibilities in these areas are met, a continuing R&D program was undertaken. The structure and content of this program has been derived from NEP objectives

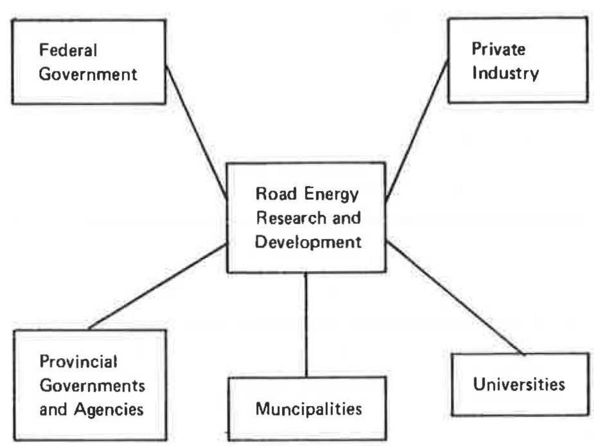

FIGURE 1 Players in road energy technology R&D.

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and priorities for transport end-use energy R&D. Research activity, in order of priority, includes

- Alternative liquid fuel use for motor vehicles,
- Conservation for intercity transport,
- Conservation for urban and regional transport, and
- Electrification and nonliquid substitute fuel use and transport.

Past, current, and projected Transport Canada R&D projects under these program headings have included all elements of the road transport system: fuels, vehicles, and highways.

The PERD approach has assisted in preventing R&D overlap and gaps within the federal government in broad terms. Within road transport energy R&D, however, there is a need for a further refinement that would *(a)* provide a framework to define R&D objectives, priorities and strategies; *(b)* place current and planned projects (federal, provincial, municipal, universities and private sector) within this framework; *(c)* permit identification of gaps or unaddressed technologies; and *(d)* provide the tool for a consensus on a national, concerted research and development effort.

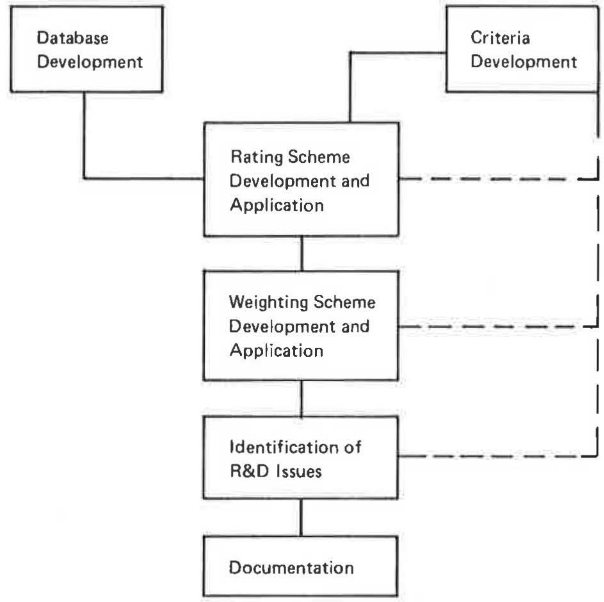

FIGURE 2 General approach to assess the effectiveness of road energy technology innovation.

METHODOLOGY

With a full appreciation of these requirements, Sypher-Mueller International was contracted to develop a framework that would enable

1. Identification of the ongoing road energy R&D being conducted in Canada, and of new technologies that show promise for Canadian application;
2. Assessment of the effectiveness of ongoing R&D in meeting national needs;
3. Updating and assessment of new R&D technologies or projects; and
4. Evaluation of road energy R&D effectiveness under a variety of current and future energy environments.

The general approach used to develop a complete technology project assessment included five basic steps as shown in Figure 2.

Step 1: The identification of federal, provincial, municipal, industrial, and university programs and projects that are currently the subject of road energy R&D. Technologies not currently the focus of Canadian R&D but which show promise for meeting national objectives were also identified. In addition, previous relevant studies were reviewed.

Step 2: The development of criteria for the objective assessment of technologies and R&D projects.

Step 3: The assessment of technologies and of specific R&D projects.

Step 4: The ranking of technologies and R&D projects using the quantitative criteria and weighting factors developed.

Step 5: The identification of gaps in R&D in each technology in federal programs, the programs of others (e.g., provinces, universities, etc.), and combined programs.

These steps form an integral part of the assessment methodology and are described in the following pages. Prior to embarking on Step 1, an overview of alternative fuel technologies was taken.

Technology Overview

Real and perceived fuel shortages in the transportation and utility or industrial sectors have historically acted as the driving force behind the development of alternative fuels and energy conservation technologies. In times of conventional fuel shortages, these sectors have been affected most immediately and widely. Consequently, it is anticipated that they will continue to drive the development of alternative fuels and affect fuel types, availability (quantities, time frames, and location), and costs, as well as the application of energy conservation technologies.

Potential New Liquid Fuels

Potential alternatives to gasoline and diesel fuel are given as follows:

- Conventional fuel equivalents—broadcut and synthetically derived diesel fuel;
- Gaseous—compressed natural gas (CNG), liquified natural gas (LNG), hydrogen, propane, butane;
- Alcohols—ethanol, methanol, alcohol-gasoline blends, alcohol-diesel fuel blends; and
- Others—electric-hybrid vehicles, vegetable oils.

Note that methanol-gasoline blends generally require the addition of higher order alcohols as cosolvent (for improving blend water tolerance characteristics). Also, the term alcohol-diesel fuel blends is used as a convenience throughout this report to describe various methods of introducing alcohols into diesel engines. Depending on specific engine configuration, alcohols can be adapted to diesel engine applications by various means, including solutions with diesel fuels, via mechanical or chemical emulsification, dual-fuel injection, fumigation into the engine air intake stream or by more extensive conversion of the engine to provide spark ignition assist. Finally, CNG and LNG include biomass and synthetically derived fuels. These fuels are most widely considered as alternative liquid and gaseous fuels for the transportation sector. Some of the fuels noted are currently used as fuels, and others are produced in commercial quantities, but not for fuel markets. Several resources are available to supply the alternative fuels. These may generally be divided into fossil fuel and renewable (e.g., solar, biomass, etc.) resources. Currently, many of the new liquid fuels are produced from petroleum, natural gas feedstocks, or both. However, they can also be derived from tar sands, coal lignite, peat, oil shale, and the renewable resources.

Step 1: Project or Program Identification

This step of the study involved

- A literature and general information search,
- Identification and review of relevant federal projects,
- Identification and review of revelant provincial, municipal, industrial, and university projects, and
- Identification and review of relevant technologies of potential interest in Canada, but not the subject of current R&D.

For each R&D project or program identified as relevant, a project summary sheet was prepared. To ensure that the projects selected were relevant, the following boundaries were applied in selecting projects for inclusion in the analysis:

1. Only projects or programs in progress after 1981 were considered. Projects completed in 1981 or earlier were not included. Projects completed in 1982 or 1983, currently ongoing or planned were included.
2. R&D was considered to include all aspects of a technology necessary for its potential for ultimate commercialization, including technical, economic or marketing, and policy issues.

Step 2: Criteria Selection, Definition, and Development

Alternative fuel technologies were divided into three major categories: technical or environmental, economic or marketing, and policy. Separate criteria were developed within each of the three categories. This allowed subjective comparisons to be made relative to the base technology using quantitative and qualitative information.

The technical and environmental category deals with technology infrastructure, technology performance, and environmental issues; the economic or marketing category deals with user cost economics, export market potential, and lead time for commercialization; and finally, the policy-related category addresses national, institutional, and energy-related issues associated with using the new fuel. Several evaluation factors, although not identified separately, were combined into others. For example, intersectoral demands are addressed by the employment impacts criterion and market demand for the alternative fuel is covered by the user cost economics, industry cost economics, and fuel supply criteria.

The criteria were defined to ensure that the approach was as objective and universal as possible: that assessment by two different agencies or individuals would yield similar results.

Step 3: Technology Evaluation

This is one of the most important steps in the methodology. Twelve alternative fuel technologies were evaluated based on a comparison to a conventional system. Many of the technologies are at different stages of development and therefore affect the speed at which they are developed and commercialized. This was taken into account in the evaluation.

Each alternative fuel technology was scored relative to a base equipment system on a scale of +2 and –2. Positive scores indicate advantages and negative scores indicate disadvantages relative to the base system. For example, positive scores for the alcohols will generally relate to their being cleaner fuels. Negative scores will also result from materials compatibility problems and their lower energy densities. The summed numerical scores (unweighted or weighted) cannot be interpreted as the value of the technology, but only as an indication of the relative potential of the technology from the viewpoint of the current knowledge base. Low scoring fuels or technologies may point to the need for R&D to improve the base of knowledge.

The ratings were established on the basis of a consensus of expected trends and the professional judgment of the study team. They are based on the state-of-the-art of the fuel technologies in the 1984 time frame. Many factors or assumptions combined to alter the ratings. The following are the major assumptions used during the fuel technology evaluations:

- The alcohol blends do not contain more than 15 percent alcohol (by volume). In the case of methanol, some cosolvent would be part of the 15 percent alcohol content to reduce the chances of separation of the methanol from the gasoline in the presence of water and to minimize vapor pressure increase.
- The use of methanol with diesel fuel may require emulsifiers or in-line emulsors.
- Methanol is a formulated fuel produced from natural gas.
- Vegetable oils are used neat in diesel vehicles.
- Synfuels are derived primarily from tar sands with properties or specifications comparable to conventionally derived base fuels.
- Electric vehicles use advanced batteries and conventional motor technology. Electricity is produced via hydroelectric or nuclear power.
- Hybrid vehicles contain a small internal combustion engine operating at constant speed in conjunction with an energy storage device such as batteries, hydraulic accumulators, or flywheels.

• The gaseous fuels (CNG), (LNG), propane, and hydrogen are envisioned for use in dedicated vehicles equipped with spark ignition engines optimized for each fuel.
• Hydrogen is produced via electrolysis of water.

The scores for the neat alcohols reflect their lower volumetric energy contents and solvent, and materials compatibility Characteristics. Without financial incentives, the alcohols will be expensive in the short-term, although in the long-term, methanol may become available at comparable costs (on an energy basis). The alcohol blends essentially exhibit the same characteristics as gasoline with some problems of materials compatibility and phase separation. Their costs should not differ significantly from the base fuel.

The synthetically derived fuels, if sufficiently upgraded, should operate well in existing vehicles, although emissions from coal- and tar sands-derived fuels are of greater concern due to their higher aromatic content. The use of synfuels may also incur higher operating and equipment costs.

One of the issues surrounding vegetable oils is quality control if segregated pipelines are not devoted to them, but their environmental impact is considerably better than diesel fuel. Another predominant problem with vegetable oils is their propensity to cause combustion deposit that can lead to clogging and other problems.

Negative scores for electric and hybrid vehicles are due primarily to poorer economics and limited vehicle range and performance. Broadcut represents a good diesel fuel substitute with a moderately adequate cetane number. However, it has a vapor pressure that is significantly higher than diesel fuel but lower than gasoline. Its primary advantage relates to lower energy usage during production in the refinery.

With respect to gaseous fuels, propane, CNG, and LNG rate well technically. The major drawbacks include their low energy densities and the lack of an adequate distribution system. Other problems relate to user acceptability and market system barriers. For hydrogen, the major problems relate to transporting it in the current distribution system, as well as to safety and resultant institutional implications. However, it does have good combustion thermal efficiency characteristics and positive environmental impacts.

Step 4: Ranking of Technologies

Overall rankings for alternative fuels technologies using unweighted and weighted scores, respectively, are given as follows.

1. Unweighted
   - CNG: 9
   - Neat methanol: 9
   - LNG: 6
   - Alcohol-gasoline blends: 6
   - Propane: 5
   - Electric-hybrid vehicles: 5
   - Vegetable oils: 4
   - Neat ethanol: 3
   - Synfuels: 3
   - Alcohol-diesel fuel blends: 1
   - Broadcut
   - Hydrogen: –6
2. Weighted
   - Neat methanol: 20
   - CNG: 18
   - Vegetable oils: 12
   - Alcohol or gasoline hybrids: 12
   - Electric or hybrid vehicles: 10
   - Propane: 9
   - LNG: 7
   - Synfuels: 4
   - Broadcut: 4
   - Neat ethanol: 2
   - Alcohol or diesel fuel blend: –1
   - Hydrogen: –26

Eleven of the twelve fuels showed positive sums for their composite score; only hydrogen showed a negative score. When the unweighted scores are considered, the new liquid fuels fall into roughly four groups with CNG and methanol constituting the top-rank group and hydrogen the lowest. Even when the weighted scores are considered, the fuel groups remain almost identical. Neat ethanol would fall into the third group with hydrogen still constituting the lowest-rank group.

The results of the alternative fuels ranking indicate that CNG and methanol represent the most promising fuel alternatives for Canada followed by LNG, alcohol-gasoline blends, propane, electric-hybrid vehicles, vegetable oils, neat ethanol, and synfuels. Finally, it should be noted that the low scores given do not indicate any inferiority, only that certain obstacles remain to be resolved before the fuel technologies can be commercialized.

In consultation with the Transport Canada Steering Committee, a rating scheme was devised for each topical category to evaluate the influence of various criteria within each evaluation category.

Step 4A: Project Assessment

Individual projects information collected in Step 1 was ranked in the same manner as technologies. In order to assess the effectiveness of R&D projects, a two-stage approach was developed. The first stage dealt with scoring alternative fuel technologies that were addressed prior to 1982. These were scored on a basis of zero, one, and two. Zero indicated that little or no information is available about the criteria; one, that some information is available and further R&D efforts are necessary to adequately address the issue; and two, that the issue has been well addressed and does not require further R&D. Thus, the issues with scores of one and zero suggest that some R&D investigation is necessary.

The second stage involved scoring each road energy R&D project against the same criteria used to assess technologies. A scale of zero and one was used. A score of one indicates that the R&D project has addressed or is addressing an issue, and a score of zero suggests that the project does not address an issue. This stage, therefore, relates to the breadth of a project. For example, if a project scores many ones, it indicates that sufficient information has been or will be generated by the

R&D NEEDS MATRIX NEW LIQUID FUELS SUBJECT AREA: METHANOL

Major Assessment Factors	Raw Material	Raw Material Transport	Fuel Manufacture	Fuel Distribution	Fuel Retailing	Road Vehicle Manufacture	Road Vehicle Use	Road Vehicle Maintenance
Technical			Fuel specification Security of cosolvent supply Octane level enhancer			Wear mechanism	Additives	Elastomers Corrosive magnesium/ aluminum
Operations				Distribution Fungibility	Storage	Systems performance Materials compatibility	Lubricating oil formulation	Engine wear
Economic			Technology/ product export potential	Impact on gas pool displacements				
Marketing			Export potential Benefit cost analysis					
Policy	Employment impacts Government financial impacts		Energy impact of production	Institutional impacts				
Regulatory								
Environmental	Air quality effect				Emissions		Emissions control	
Safety/Health		Education of fire-fighting personnel Modification of fire-fighting equipment			Leak detection Toxicity Explosion hazard		Crash vulnerability	

FIGURE 3 Example of an R&D needs matrix for methanol.

R&D project relative to the various criteria. In other words, the R&D project is assessing many issues concurrently. Multiplying each score by the weighting factors for each criterion and then summing up the score provides relative ranking of the R&D projects in terms of scope and weight of criteria addressed. The second stage relates to the amount of information currently being generated by the various road energy R&D projects, and does not indicate whether an issue has been adequately described.

This step of the methodology leads to total project scores that give the relative impact of each R&D project. The exercise can also be used to assess proposed projects. This step leads to the GAPS analysis—the identification of those areas that have not been satisfactorily addressed.

Step 5: Analysis of Gaps

From the technology and project assessment, an overview of R&D needs in the alternative fuels area of road energy was developed. Matrices were constructed for each fuel (Figure 3) summarizing areas needing further research and development.

The matrix format permits the use of each matrix as a multiyear work plan; for full commercialization potential of a fuel technology, the needs matrix should be completely void of entries. Working towards this target by addressing issues and removing from the matrix provides a framework for R&D in each fuel technology. By examining all the matrices, it is possible to develop a picture of R&D programs that encompass several fuel technologies.

The needs matrices also tend to put technical R&D in perspective. Although traditional R&D often focusses on the technical issues, other issues are equally important if the potential for use of a fuel is to be fully exploited. Many of the less glamorous but important aspects of the overall R&D picture will be carried out only by government, including issues relating to government policy, regulations, environmental impact, safety, and health.

Based on the matrix analysis of the 12 alternative fuel technologies, overall Canadian R&D needs fall into the following five areas:

1. R&D is required for regulatory changes (federal and provincial) necessary to provide an environment for new liquid fuels.

2. Benefit-cost models are required for general application to new fuels and new technologies, taking into consideration all aspects of a fuels impact. As a generalization, there is a shortage of knowledge on the national benefits and costs of the use of alternative fuels. The models should be readily modifiable to cope with changing relative costs of petroleum and new fuel technologies.

3. Development of minimum acceptable vehicle performance characteristics guidelines in terms of cold start, acceleration, and drivability could provide a useful benchmark for R&D into individual fuels.

4. Research into leak detection, refueling systems, toxicity, crash vulnerability, and fire-fighting equipment needs including development of a national training and information package for fire fighting each one of the new fuels would enhance safety.

5. Continued development of fuel specifications and labeling requirements is needed.

FUTURE OUTLOOK

In the area of alternative fuel technologies, the gaps analyses will serve as the parameters for setting priorities for future expenditures. These gaps will form part of a comprehensive transportation R&D strategic plan for Transport Canada. Now that gaps have been identified in a rational manner, what remains to be done is to determine in consultation with the provinces, industry, and others what R&D should be conducted or supported federally and what projects are best tackled by others.

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Drive-Up Windows, Energy, and Air Quality

JON D. FRICKER AND HUEL-SHENG TSAY

The increasing popularity of drive-up windows as a means of conducting business brings with it questions of the best use of this kind of facility. In addition to studies on the best designs for drive-up facilities, there is the question of the fuel consumption and automobile emissions associated with this kind of operation. At what queue length would a driver save fuel by parking his car and walking into the facility to conduct business? What data and methods do policy makers need to be aware of to understand drive-up windows in the context of a fuel shortage or an air quality emergency? Data collected at a fast-food restaurant is used in this paper. It was found that a very large percentage of the fuel and emissions associated with the drive-up queue could be saved if people would forego the convenience and time savings usually provided by drive-up facilities.

Drive-in theaters and old-fashioned drive-in restaurants with carhops may have become a thing of the past, but other forms of transactions are being conducted directly from vehicles with increasing regularity. Many fast-food restaurants and banks offer a drive-up window, so that business may be conducted without ever shutting off the engine. Similar services, although not as common, are provided by dry cleaners and even funeral homes. The design *(1)* and queueing *(2)* aspects of drive-up service have been addressed in a number of papers. The issue of efficient use of motor vehicles in the drive-up environment is of special interest. Regarding fuel efficiency and vehicle emissions, is waiting in a line of vehicles to place and collect your fast-food order always better than parking your car and restarting it later? In an era of stable gasoline prices, this topic may sound anachronistic. However, air quality is an ongoing concern, and there may come a time when such information is again important to energy-conscious policy makers. In fact, for frequent patrons of establishments with drive-up windows, even a modest difference in fuel use may gradually add up to noticeable cost savings if they regularly apply the guidelines developed in this paper.

METHOD OUTLINE

The analysis begins with the accumulation of data regarding vehicle movements in the special environment of a drive-up facility. Certain kinds of data are needed regarding fuel consumption and vehicle emissions (by vehicle engine size, if possible) for

1. Idling mode,
2. Move-up movement in a queue, and
3. Restart of an engine that has been shut off for a specific length of time.

The intent is to combine the elements of a representative queueing model with data on vehicle operation and drive-up window service to develop relationships of the sort hypothesized in Figure 1.

It is likely that these relationships vary with vehicle size and type, and drive-up facility type, configuration, and service rate. Nevertheless, the goal is a simple, practical method whereby

1. An individual driver can make an informed decision as to whether to join a queue, park his car, or neither if his own fuel savings or reduction of emissions are his primary concern.
2. A public policymaker can use average or aggregated values to decide whether it is in the public interest under certain conditions (e.g., fuel shortage or smog alert) to encourage, prohibit, or revise drive-up operations.

The intended method is reminiscent of the rule of thumb concerning an idling automobile engine at a railroad grade crossing blocked by a passing train. The suggestion is to estimate how long the car has to idle, and if that time exceeds some critical value, the engine should be shut off to save fuel. This critical value has been given as anywhere from 30 sec to 2 min, but it is apparently not documented.

DATA SEARCH

The vehicle performance data needed for this analysis are rather specialized, and therefore difficult to obtain. At the time

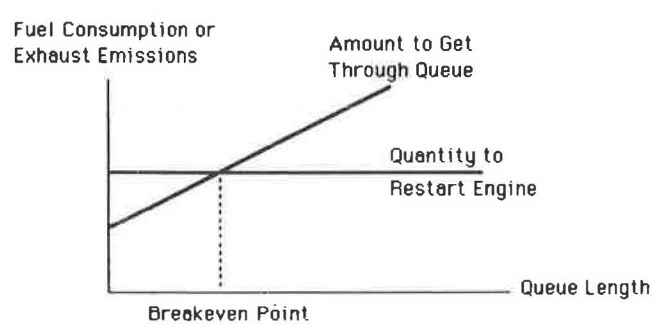

FIGURE 1 Queue length at which idling becomes ill-advised.

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of this study, idling fuel consumption and emission values were available from several reports *(2–9)*, but these were sometimes based on vehicles manufactured in earlier years. The move-up and restart values were especially hard to find, but after a lengthy literature search and a series of telephone calls to fuel and emissions experts, the values in Table 1 were adopted. The numbers shown are the result of an effort to translate existing data into numbers that fit the specific modes of vehicle operation pertaining to this study.

TABLE 1 FUEL CONSUMPTION AND EMISSION RATES

Operation Mode	Fuel Use	Exhaust Emissions HC	CO	NO_x
Idling	0.65 gal/hr[a]	0.16	2.43	0.05 lb/hr[a]
Move-up	0.002 gal/cycle[b]	0.2	2.31	0.045 lb/hr[c]
Restart	0.0017 gal/start[b]	0.0036	0.005	0.0002 g/start[d]

[a]See *(6)*.
[b]See *(3)*.
[c]See *(1)*.
[d]See *(5)*.

An interesting immediate finding is the extremely low fuel requirement for a "hot start," that is, an engine restart within an hour after turnoff. At 0.65 gal/hr (Table 1), a car can idle for only 9.4 sec before exceeding the fuel needed to restart. In fact, according to Claffey *(3)*, 0.0017 gal per start may be a high estimate for hot starts:

> The engine draws no fuel from the carburetor bowl during engine cranking operations. Apparently the engine starts using fuel vapor already in the firing chamber or in the intake manifold. This could be a helpful note for fuel conservation, since drivers should not hesitate to turn off their engines instead of letting them idle at stops because they mistakenly think extra fuel will be used to crank the engine to re-start.

Although the fuel breakeven point is only 9.4 sec, the breakeven points for emissions are also surprisingly low: 5.6 sec for hydrocarbons, 61 sec for carbon monoxide, and 31.5 sec for nitrogen oxide. If fuel saving and air quality are an individual's top priorities, parking the car and walking into the restaurant is the obvious choice. Note that subsequent to the completion of this study, a report on passenger vehicle fuel consumption and emission estimates *(10)* was published, citing values in substantial agreement with those used in this paper.

The extent to which actual usage of drive-up facilities consumes fuel and adds to air pollution remains to be determined. Generally, such facilities are of considerable convenience and time savings, but at what cost? For the fast-food restaurant shown in Figure 2, 245 vehicles were observed entering the parking lot during the two noontime hours in which data were collected. The data collection was undertaken as follows:

1. Record the license plate number of an entering vehicle and its time of entry.
2. If the vehicle joins the drive-up queue, record that time and the number of vehicles ahead of it before the ordering location.

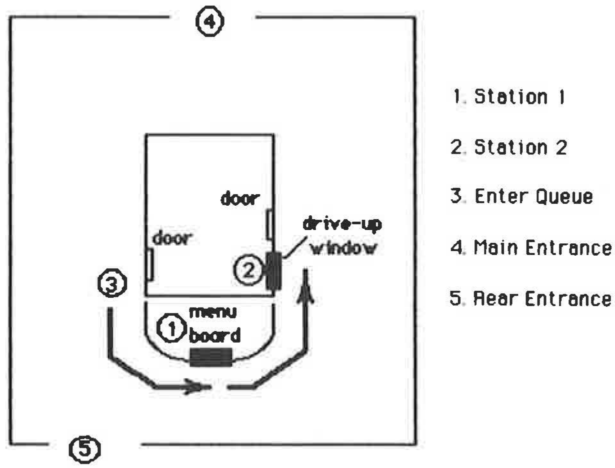

FIGURE 2 Layout of a drive-through facility.

3. After an order has been placed, record the number of vehicles queued at the pick-up window.
4. Record the time at which the vehicle leaves the pick-up window.
5. Record the time at which the vehicle leaves the parking lot.

Based on observations made October 2, 1984, it was determined that

- Total number of vehicles using the drive-up facility during the 2-hr period of observation was 131 (53.5 percent of the 245 arrivals);
- Average elapsed time between entering and leaving the parking lot for customers who ate inside the restaurant was 21.85 min;
- Average elapsed time between entering and leaving the parking lot for users of the drive-up facility was 3.73 min or 223 sec;
- Average time spent in the drive-up lane was 3.54 min or 212.6 sec;
- Average time spent in the drive-up lane, if there was no queue at Station 1 at the time of arrival was 113 sec;
- Average queue length at Station 1 (the menu board) was 1.65 vehicles; and
- Average queue length at Station 2 (the pickup window) was 1.46 vehicles.

A convenient way to measure service rate at Station 2 is in terms of the rate at which vehicles leave the pick-up window, as long as a queue continues to exist. For the facility we observed, this service rate is 71.7 vehicles per hour, or an average service time of 50.2 seconds per vehicle. Because a vehicle approaching Station 1 with no queue can expect to spend 113 seconds in the drive-up lane, the service time at Station 1 can be defined as:

$$1/\mu_1 = 113 \text{ sec} - 50.2 \text{ sec} = 62.8 \text{ sec}$$

This translates into a service rate, μ_1, of 57.3 vehicles per hour.

The data also helped to determine that the average vehicle experiences 4.04 moveups in the drive-up lane. The time not spent moving up is spent idling, at 0.65 gal/hr. No driver was ever observed shutting off his vehicle's engine while in the queue. Additional data collected indicated that it required an average of 8.4 sec per moveup in the queue. These values are used to modify idling time, to avoid double counting:

Moveup time: (131 vehicles x 4.04 moves/vehicles x 8.4 sec/move)/2 hr = 2222.8 sec = 0.6174 hr.

Total time spent (per hour) in drive-up lane: (131 vehicles x 212.6 sec)/(2 x 3600 sec/hr) = 3.868 hr.

Total idling time: 3.868 hr – 0.617 hr = 3.251 hr.

Values from Table 1 can then be used to carry out the following calculations:

Fuel consumption during moveups: (131 vehicles x 4.04 moves/vehicles x 0.0002 gal/move)/2 hrs = 0.0529 gal/hr.

Fuel consumption during idling time: 0.65 gal/hr x 3.251 hr = 2.113 gal.

Table 1 then allows an estimation of noon hour emissions.

Carbon monoxide (CO): (2.31 lb/hr x 0.6174 hr) + (2.43 lb/hr x 3.251 hr) = 9.326 lb

Hydrocarbons (HC) (0.2 lb/hr x 0.6174 hr) + (0.16 lb/hr x 3.251 hr) = 0.6436 lb

Nitrogen oxide (NO_x): (0.045 lb/hr x 0.6174 hr) + (0.05 lb/hr x 3.251 hr) = 0.1903 lb

QUEUEING MODEL

It would be more convenient if the vehicle movements observed and translated into energy and emission values in the detail shown in the preceding section could be approximated through use of an appropriate model. The data collected for the calculations required five observers. With only one or two observers, it would be possible to develop a dataset adequate for use in a queueing model intended to represent the operation of the drive-up facility. The average arrival rate λ (vehicles per hour) and service rates μ_i (vehicles per hour for each service location or station i) can be based on data collected with moderate effort at the stations. These parameters λ and μ_i are sufficient, under the proper conditions, to form the basis for a useful queueing model.

The queueing process at a drive-up window, shown in Figure 2, is a special case of an open Jackson network *(11)* in which all the departures from service station i go to service station i + 1, i < k, and the departures from station k leave the network. This type of network is called tandem. Most of the existing fast-food systems have two stations for drive-through service such as a menu board and a pick-up window (Figure 3). Tandem queueing models have been used to model traffic flow with k = 2.

Under the following assumptions, a tandem queue with k = 2

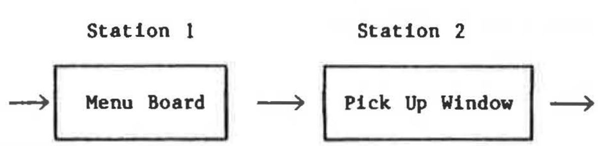

FIGURE 3 Queueing process of drive-up window service.

can be satisfactorily modeled by standard queueing equations: (a) $\lambda < \mu_1$, (b) $\lambda < \mu_2$, (c) $\mu_1 < \mu_2$, where (d) interarrival and service times are exponentially distributed and (e) independent of each other, and (f) the queues have infinite capacity. However, it is quite likely that none of these conditions (a) through (f) will hold throughout a typical peak period at a two-station fast-food tandem queue:

- For (a) and (b), peak period vehicle arrivals frequently exceed the service rate of Station 1 or Station 2, or both. In the case study, $\lambda > \mu_1$.
- For (c), Station 2 is normally where the food is both paid for and picked up. Together, these two activities often take more time than placing an order at Station 1.
- For (d), (e), and (f), arrival times can be affected by traffic controls or conditions on the adjacent streets, biasing the interarrival time distribution. Furthermore, λ at Station 2 equals μ_1 during peak periods, which may transmit any bias in the λ at Station 1. Finally, it is common for $\mu_2 < \mu_1$, causing the Station 2 queue to grow and prevent service at Station 1. If an excess queue between Stations 1 and 2 develops, this is known as a tandem queue with blocking. This is a very difficult problem, for which no solution technique has yet been published.

The recent introduction of three-station systems, with separate windows to (a) take money and (b) deliver the order, may lead to cases in which $\lambda < \mu_1 < \mu_2 < \mu_3$ holds a significant fraction of the time, but this has not been studied. For most cases, queueing analysis using standard expressions based on λ and μ_i must be replaced by simulation or graphic techniques. For this paper, conclusions will be based on the data collected.

SERVICE AND QUEUE TIME

It is unlikely that any significant number of individuals will forgo any time savings and convenience that use of a drive-up window may offer, just to reduce fuel use and exhaust emissions. This section considers the time factor, as well as the fuel and air quality costs that follow from a decision to use the drive-up facility. Table 2 gives the average time spent for a range of queue lengths in the two-station drive-up lane that was studied. The duration in the lane increases at a decreasing rate up to a queue length of four. The expected time actually decreases somewhat, which must be explained by the small number of observations at longer queue lengths. Any time value in Table 2 can be converted into fuel and exhaust emission equivalents, as was demonstrated earlier in this paper.

Based on Table 2, if a driver approaching Station 1 (the menu board) is not willing to spend more than 4 minutes in the drive-up system, that person ought not to join a queue at this menu board if it is of size two or larger. From the point of view of fuel consumption, even if a driver approaches the menu board unimpeded, he is destined to burn more than 10 times as much fuel (0.0210/0.0017) as if he had parked.

IMPLICATIONS

The rule for an individual's decision to use a drive-up facility is clear cut: If fuel saving and air quality are most important, park

TABLE 2 AVERAGE TIME SPENT IN DRIVE-UP FACILITY

No. of Cars in Station 1 Queue	Total Time in Drive-Up System (min)	Fuel Use Idling (gal)	Fuel Use Moving Up (gal)	Total Fuel Consumption (gal)
0	1.88	0.0190	0.002	0.0210
1	2.83	0.0261	0.006	0.0267
2	4.00	0.0358	0.010	0.0458
3	4.48	0.0380	0.014	0.0520
4	5.01	0.0422	0.016	0.0582
5	4.85	0.0389	0.018	0.0569
6	4.60	0.0347	0.020	0.0367

the car and walk in. Usually, however, time and convenience are more important to the individual. A queueing analysis of the service for walk-in customers would provide the basis for a comparison with Table 2, leading to an informed time-minimizing decision.

To society as a whole, drive-up services translate into greater fuel use and automotive emissions. For the 2-hour case study described in this paper, the vehicles in the drive-up line burned fuel at a rate of 2.1659 gal/hr, which is 2.113 gal/hr for idling and 0.0529 gal/hr to move up, as calculated earlier in this paper. An average of 65.5 restarts per hour translates to 0.1114 gal/hr, which is only 5 percent as much. The Lafayette, Indiana, area (population 75,000) has over 50 drive-up windows at restaurants, banks, and dry cleaners. Expanding the scope of the analysis to the full business day leads to a potential fuel saving of several 100 gal per day in this area alone.

The closing of drive-up facilities will not yield the same reductions in energy waste and air pollution as a successful ridesharing program. Neither is it likely to be well received by the businesses involved or their customers. (Exceptions could be made for handicapped individuals, in the same spirit that parking spaces are reserved for them.) However, in a serious energy or air quality emergency, this kind of operation should be asked to make a contribution to the community's welfare. A 95 percent saving with few hardships, even in an activity of modest scale, should not be overlooked.

ACKNOWLEDGMENTS

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Travel Characteristics and Transportation Energy Consumption Patterns of Minority and Poor Households

MARIANNE MILLAR, ROBERT MORRISON, AND ANANT VYAS

Results of a recent investigation of travel behavior and transportation energy use by minority and poor households are presented and interpreted in terms of the known effects of household demographic characteristics on vehicle ownership and travel demand. When income and residential location are controlled, black (and to a lesser extent, Hispanic and poor) households were found to have fewer vehicles regularly available than did comparable white or nonpoor households, and their vehicles tended to be older and larger, and therefore having significantly lower fuel economy. Blacks were also found to rely more heavily than other groups on public transportation and carpools for their work travel and, partly as a result, to have significantly longer average travel times. Because of depressed vehicle-ownership rates and less fuel-efficient vehicles, the average black, Hispanic, and poor household travels significantly fewer miles per year but consumes somewhat more fuel than does the average white or nonpoor household. The major finding in this study of significant racial differences in vehicle availability and use by low-income central city households challenges the conventional wisdom that racial variations arise solely in response to differences in income and housing location. It was concluded that because cross-sectional data sets cannot capture the dynamics of income, they cannot identify the persistently poor who tend to be concentrated in certain demographic subgroups (primarily black and female-headed households). Because capital goods and the resources needed to keep them in efficient working order are usually acquired in relatively prosperous years, households for which prosperity is rare or nonexistent may be expected to have depressed rates of vehicle ownership and use, and their vehicles may be expected to have relatively lower fuel economy than seemingly comparable but only temporarily poor households.

Selected results from a research program being conducted at Argonne National Laboratory (ANL) for the U.S. Department of Energy's Office of Minority Economic Impact are presented. In keeping with that office's mandate, the program is directed toward (a) determining the energy consumption and expenditure patterns of minority groups relative to those of other population groups, (b) assessing the impacts of existing or proposed government energy policies and programs on minorities, and (c) identifying options for modifying those policies and programs to alleviate anticipated hardships, particularly on low-income individuals.

The research program has documented patterns of residential energy demand and expenditures by minority and poor households and has developed a series of analytical tools to measure the effects of energy policies and programs on those patterns *(1–3)*. Because transportation energy (expressed as fuel used in private vehicles) accounts for more than one-half of the energy expenses of the average U.S. household ($1,317 from a total of $2,380 in 1983), recent research has begun to focus on identifying the characteristics of travel and fuel consumption, as well as expenditures by minority and poor households *(4)*. To date, three transportation-related reports have been completed or are in progress. One documents patterns of vehicle ownership, travel, and transportation fuel use, as well as expenditures by minority and poor households, and is summarized in this paper *(5)*. The other two reports assess the impacts of potential energy conservation strategies on minority and poor population groups and the effect of past fuel shortages on those groups *(6,7)*.

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BACKGROUND

Approach

This paper is primarily expository. Travel characteristics and transportation fuel consumption patterns of minority households (as defined by race or ethnicity) are described and the patterns are compared with those of otherwise equivalent nonminority households—controlling is made for income, residence location, and, in some cases, age of householder. Significant differences between minority and nonminority households, based on standard statistical tests, are identified and interpreted.

The analytical approach consisted of a literature review and survey analysis. Selected aspects of minority travel behavior and fuel use reported in previous studies were reviewed, as were similar studies of low-income households *(8–11)*. The review indicated that although certain aspects of the subject have been examined in earlier work, those investigations were either tangential to the main focus or were limited to a discrete subset of travel behavior (e.g., the journey to a job). No comprehensive analysis of overall travel behavior and fuel use by minority and poor households was identified in the literature.

In this paper, data on households—the basic unit of travel demand and fuel use—are displayed for five population groups based on survey respondents' self-reporting of their household income and the racial or ethnic origin of the householder. These groups are (a) blacks (including black Hispanics); (b) Hispanics (excluding blacks); (c) whites (excluding Native Americans, Asians, or Pacific Islanders); (d) poor (all blacks, Hispanics, whites, or other ethnic groups whose household income is less than 125 percent of the federally defined poverty threshold); and (e) nonpoor (all other households).

Because surveys generally report income categorically, the survey records processed at ANL were assigned to poor or nonpoor groups based on the federal poverty definition for the year of interest, rounded to the nearest income breakpoint. Poor and nonpoor data sum to national totals. For survey data processed at ANL, the white, black, Hispanic, and other categories were also made mutually exclusive so they also would sum to national totals. (Because Hispanics may be of any race, survey results for whites, blacks, and Hispanics reproduced from other sources do not sum to national totals.)

Data Sources

Primary data sources were the 1977 Nationwide Personal Transportation Study (NPTS), the 1979-1981 Transportation Panel (TP) of the Residential Energy Consumption Survey (RECS), and the 1980 Annual Housing Survey (AHS) *(12–14)*. Secondary sources incorporated through published reports included the 1970 and 1980 Department of Commerce censuses, the 1972 and 1980 Consumer Expenditure Surveys, the 1983 Residential Transportation Energy Consumption Survey (RTECS), and the 1969 NPTS *(4,8,15–19)*. Published documents were used instead of the RTECS public use tape because it was unavailable at the time of the analysis. For a more complete discussion of the characteristics, strengths, and limitations of our major data sources, see *(5)*.

Although survey analysis was clearly the most appropriate analytical method for this study, it does have inherent limitations. Most notably, because none of the data sources oversampled any racial or ethnic group, even the numerically largest category of interest—black households—represents less than 10 percent of the observations of any survey and may be subject to considerable sampling error. Although sampling error probably did not prevent identification of major differences between groups, it did constrain the analysis of more subtle, but still potentially significant, differences. For example, in the TP data set, only 40 to 80 black households were sampled each month and there was no control for multiple (and thus highly correlated) observations of the same household. Therefore a cross-classification of monthly TP data by no more than one parameter at a time (e.g., race, income, or residence location) was made, and the data was smoothed to reduce the high month-to-month variation in subgroup means.

National data bases such as those used in the analysis cannot depict the fine details of travel patterns (particularly those that reflect local conditions), and limited sampling constrains further probing for underlying factors that differentiate the travel behavior of poor and minority households. Nonetheless, national data do provide the raw material for a reasonably complete sketch of travel and fuel use. That sketch reveals several statistically significant differences, some attributable to variations in demographics, others at least partially inexplicable at this stage of analysis. Further detail would require the use of local data bases that would increase comprehensiveness but reduce the ability to generalize to national patterns and trends.

VEHICLE AVAILABILITY

The number and types of private vehicles available to households have an important bearing on the quantity and modal distribution of household travel and, ultimately, on their fuel use. Households with no vehicles generate extremely little vehicular travel (even considering borrowing from friends or relatives), while multivehicle households make more than twice the average number of daily trips *(12)*. The NPTS and TP data reveal significant differences in vehicle availability between white and minority households and between poor and nonpoor households.

Vehicles Per Household

Research has repeatedly shown that vehicle availability is related to household size and composition, income, and residence location. In 1980, households with incomes under $10,000 had an average of 0.95 vehicles, compared to 2.47 vehicles in households with incomes over $35,000. The variation widened when disaggregated by residence location from 0.6 for low-income households in central cities of standard metropolitan statistical areas (SMSAs) to 2.65 for high-income rural households *(14)*. Vehicle availability also varied from 1.17 for elderly households (those with household heads 60 or more years old) to 1.78 for nonelderly households, and again the variation widened by location (from 0.83 for elderly households in central cities to 1.94 for nonelderly suburban households) *(14)*.

Because disproportionate shares of minority households reside in central cities and have low incomes, as a group they may be expected to have below-average vehicle availability *(16)*. However, this should be partly offset by the lower proportion of elderly householders in minority households *(15)*. As shown in Table 1, however, even when income, residence location, and age of household head, or householder, are controlled, large differences in vehicle availability persist between white and minority households, as well as between poor and nonpoor households (see also Figure 1). Because (a) the poverty definition is related to family size, which is also related to vehicle availability, and (b) elderly households are omitted from these comparisons, certain categories of poor households have more vehicles, on average, than nonpoor households. Differences are highlighted by comparing vehicle-ownership distributions for each of the population groups. As shown in Figure 2, more than 36 percent of black households and 27 percent of Hispanic households were without vehicles in 1977, compared with only 12 percent of white households. White zero-vehicle households were significantly more likely to be elderly than were their black or Hispanic counterparts (64 percent versus 35 percent and 30 percent, respectively). Because the elderly are more likely to live in smaller households with fewer licensed drivers and make fewer work trips, differences in age structure between white and minority house-

TABLE 1 AVERAGE NUMBER OF VEHICLES PER NONELDERLY HOUSEHOLD, BY RESIDENCE LOCATION AND HOUSEHOLD INCOME FOR EACH POPULATION GROUP, 1980

Household Characteristic	White	Black	Hispanic	Poor	Nonpoor	All Households
SMSA Central City[a]	1.50	0.96	1.02	0.67	1.49	1.31
<$10,000	0.90	0.50	0.53	0.63	0.83	0.70
$10,000-19,999	1.28	1.04	1.15	1.14	1.20	1.20
$20,000-34,999	1.79	1.59	1.74	NA	1.73	1.73
>$35,000	2.22	2.01	b	NA	2.20	2.20
SMSA Suburbs	2.00	1.37	1.68	1.39	2.01	1.94
<$10,000	1.42	0.73	1.18	1.36	1.23	1.32
$10,000-19,999	1.64	1.32	1.47	1.75	1.59	1.59
$20,000-34,999	2.10	1.81	2.11	NA	2.08	2.08
>$35,000	2.53	2.25	2.66	NA	2.52	2.52
Non-SMSA	2.00	1.27	1.68	1.33	2.05	1.92
<$10,000	1.42	0.78	1.12	1.27	1.33	1.29
$10,000-19,999	1.83	1.60	1.75	1.93	1.79	1.80
$20,000-34,999	2.25	2.02	2.27	NA	2.24	2.24
>$35,000	2.74	2.08	2.54	NA	2.71	2.71
All Households	1.91	1.13	1.43	1.15	1.91	1.78

[a]SMSA = standard metropolitan statistical area.
[b]Not reported because of a large variance in observed data.
Source: Ref. 14. Standard errors are not shown because they cannot be computed from the data tape, and published documentation is not yet available.

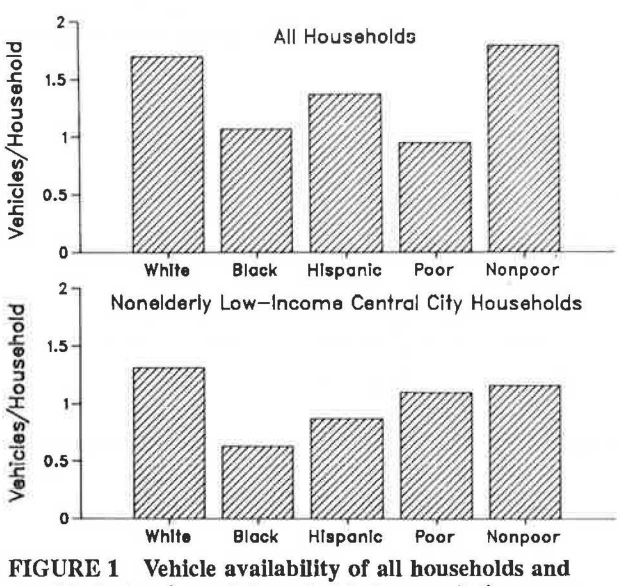

FIGURE 1 Vehicle availability of all households and nonelderly low-income households by population group, 1980.

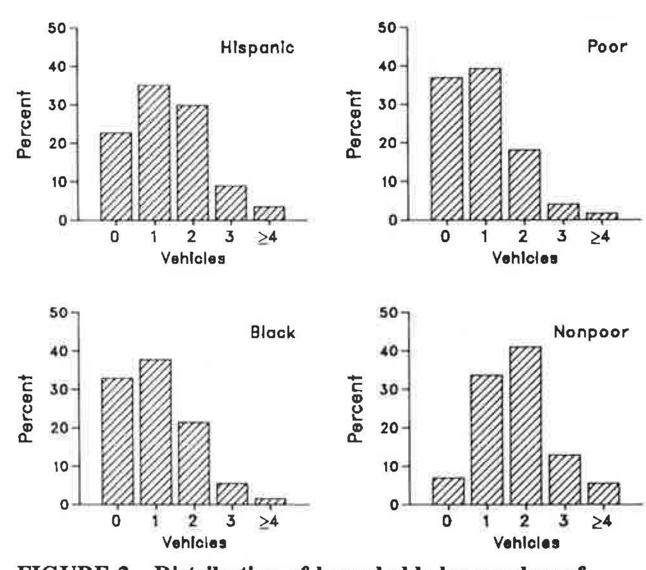

FIGURE 2 Distribution of households by number of vehicles available for each population group, 1977.

TABLE 2 VEHICLE-MILES PER HOUSEHOLD FOR SINGLE-VEHICLE NONELDERLY LOWER-INCOME HOUSEHOLDS BY POPULATION GROUP, 1977

Household and Location	White	Black	Hispanic	All Households
All Households with				
Incomes <$7,500	10720	7392	10096	10223
	(837)	(780)	(1582)	(657)
All Low-Income Households				
SMSA Central City	11716	5587	8179	9869
	(2219)	(675)	(1641)	(1463)
SMSA Suburbs	11411	11253	11138	11339
	(1185)	(2546)	(1973)	(1002)
Non-SMSA	9533	7700	[a]	9776
	(963)	(1491)		(863)

Note: Numbers in parentheses are standard errors.
[a]Not reported because of a large variance in observed data.
Source: Ref. 12.

holds may obscure other important differences in travel patterns and fuel use. Therefore, certain of the comparisons in this paper (Tables 1 and 2, and Figures 3 and 4) are limited to nonelderly households.

Although the distinctive demographic characteristics of minority and poor households explain some of the variation in their vehicle availabilities, one must look further to explain remaining differences. Clearly, most of minorities' reduced vehicle availability is in lower-income households regardless of residence location. Some may be attributable to local variations in the spatial distributions of low-income white and minority households and to the relative accessibilities of their neighborhoods to public transportation. Similarly, relative densities may vary between predominantly white and minority neighborhoods, and this may influence the supply of off-street parking and other factors that make private-vehicle ownership more or less desirable. However, none of these factors explains why the differences tend to lessen and ultimately disappear as income rises.

How do low-income minority households differ from low-income white households? Initially, it was hypothesized that the compositions of white, black, and Hispanic households in the lowest income category (under $7,500 in 1977 dollars) may differ. If minority households tend to have fewer adults (or more specifically, fewer licensed drivers), vehicle ownership could be expected to be lower than in white households. As shown in Figure 3, however, systematic differences in the average number of vehicles per licensed driver, when income and residence location are controlled, suggest that household composition is probably not a key factor.

It was next speculated that perhaps white, black, and Hispanic households in the lowest income category have systematically different average incomes. If large enough, these differences could make it impossible to control fully for income. Using 1980 data *(14)*, mean incomes were calculated for each of four income categories (<$10,000, $10,000–19,999, $20,000–34,999, and ≥$35,000) and compared across population groups. Except in the highest income group, all differences were approximately what might be expected in survey data

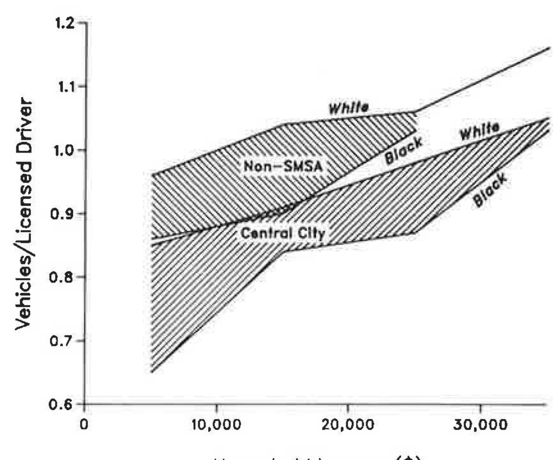

FIGURE 3 Vehicles per licensed driver in nonelderly black and white households by income category and residence location, 1977.

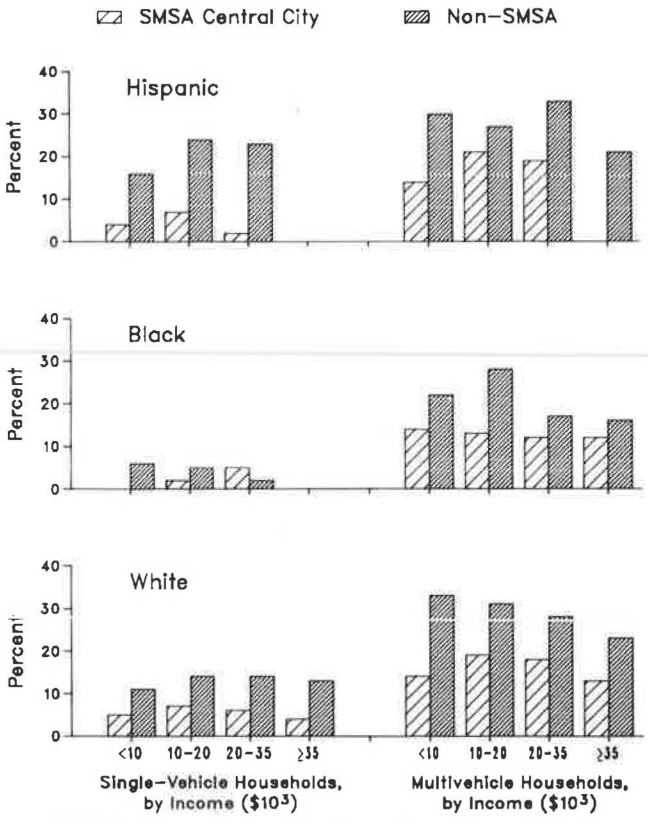

FIGURE 4 Percentage of trucks and vans in vehicles available to white, black, and Hispanic single- and multivehicle nonelderly households, 1980.

(generally ±1 percent). Hence, this too was rejected as highly unlikely.

A related but far more plausible hypothesis was then framed: if income fluctuations temporarily place many generally middle-class households in the low-income category, perhaps that category is much more heterogeneous than is apparent in cross-sectional data sets. Compared with the "persistently poor," who have extended periods of low annual income, these "temporarily poor" households can be expected to have more accumulated wealth (including vehicles) and greater access to capital and to retain a lifestyle more in keeping with their long-run average incomes. The growing body of research using a decade of longitudinal data from the University of Michigan's ongoing Panel Study of Income Dynamics (PSID) strongly supports this hypothesis *(20)*. Only 7 percent of the PSID sample had total money incomes below the federally defined poverty threshold in 1978, but nearly 25 percent fell below that threshold in at least one of the prior 10 years *(20)*. These temporarily poor are not very different from the U.S. population as a whole. By contrast, the persistently poor (those below the poverty threshold in at least 8 of the prior 10 years) are heavily concentrated in two overlapping groups—black and female-headed households *(20–22)*. Perhaps because of this concentration, the mean duration of poverty periods recorded in PSID varies from 3.4 years for whites to 6.5 years for blacks *(21)*. Cross-sectional data sets, by definition, obscure these kinds of important distinctions in long-run income (particularly at the lower end of the range), making it extremely difficult, if not impossible, to control for this key parameter in data analysis. Thus, the two groups, low-income blacks and low-income whites, may not be strictly comparable.

Vehicle Characteristics

The vehicles available to minority and poor households tend to be somewhat older and substantially less fuel-efficient than those available to white households. As shown in Table 3, vehicles in minority households were, on average, 0.6 to 0.7 years older than those in white households in 1977 *(12)*. Much of the difference appears related to income (vehicles in poor households were more than 2 years older than those in nonpoor households). However, when both income and age of householder are controlled, the difference widened in the lowest income group. Again, this may be attributable to differences in long-run average incomes of white and minority households.

Figure 5 shows that in 1983 white households were more likely to have four- or six-cylinder models than were black or Hispanic households. Their automotive fuel economy was 2.2 mi/gal (mpg) greater than in black households and 1.5 mpg greater than in Hispanic households. Truck fuel economy was about the same *(4)*. Because whites and Hispanics tend to have substantially more trucks (with lower fuel economy) than do blacks (Figure 4), the average fuel economy of all vehicles available to minorities is somewhat closer to that of whites (differing by 1.5 to 1.6 mpg).

Evidence suggests that the gap in fuel economy between vehicles in black and white households has grown since 1979. Figure 6 displays average fuel economy for vehicles in white, black, and poor households over the 28 months from June 1979 through September 1981 *(13)*. While a slight upward trend is seen for vehicles in white households (averaging 4.7 percent when calculated over the three summer driving seasons), no such improvement is apparent for vehicles in black or poor households. In fact, their average fuel economies dropped by a comparable margin.

Vehicle Use

Household use of vehicles (in annual miles per vehicle) tends to vary with household income, residence location, and age of householder, and with the number of vehicles available to the household. The lower use of vehicles in black, Hispanic, and poor households (Table 4) appears to reflect the distinctive distributions of each of the subpopulations with respect to these variables. However, when both income and residence location are controlled, the data reveal significant differences in miles per vehicle between blacks and whites, particularly for low-income households in central cities. Because of depressed vehicle-ownership rates, one would expect minority households to have somewhat higher vehicle use, on average, than that of white households with comparable incomes. This is true for Hispanics, but not for blacks. Among low-income households in central cities, black-owned vehicles are driven less than two-thirds as far as white-owned vehicles [4,097 versus 6,819 mi per year *(12)*] as shown in Figure 7. Presumably, lower use in black households reflects a series of factors, including (a) local conditions that reduce the attractiveness of

TABLE 3 AVERAGE AGE OF HOUSEHOLD VEHICLES BY HOUSEHOLD CHARACTERISTICS FOR EACH POPULATION GROUP, 1977

Householder Age and Household Income	White	Black	Hispanic	Poor	Nonpoor	All Households
Household Income						
<$7,500	8.1	8.9	8.8	8.7	7.7	8.2
(.08)	(.21)	(.36)	(.10)	(.10)	(.07)	
<60 yr	7.8	8.7	8.9	8.3	7.6	8.0
(.10)	(.28)	(.39)	(.11)	(.14)	(.09)	
≥60 yr	8.4	9.1	[a]	9.4	7.8	8.5
(.12)	(.30)		(.17)	(.15)	(.11)	
$7,500-14,999	6.8	6.8	7.4	7.6	6.7	6.8
(.05)	(.17)	(.27)	(.17)	(.05)	(.05)	
<60 yr	6.9	6.6	7.3	7.5	6.7	6.8
(.06)	(.18)	(.27)	(.18)	(.06)	(.06)	
≥60 yr	6.7	8.1	[a]	[a]	6.8	6.9
(.12)	(.49)			(.12)	(.12)	
$15,000-24,999	6.2	5.9	6.1	NA	6.1	6.1
(.05)	(.20)	(.28)		(.05)	(.05)	
<60 yr	6.2	5.7	6.1		6.1	6.1
(.05)	(.20)	(.29)		(.05)	(.05)	
≥60 yr	6.2	[a]	[a]		6.3	6.3
(.15)				(.15)	(.15)	
≥$25,000	5.4	5.5	[a]	NA	5.4	5.4
(.06)	(.30)			(.06)	(.06)	
<60 yr	5.4	5.5	[a]		5.4	5.4
(.07)	(.31)			(.06)	(.06)	
≥60 yr	5.5	[a]	[a]		5.5	5.5
(.18)				(.18)	(.18)	
All Households	6.5	7.1	7.2	8.5	6.3	6.6
(.03)	(.11)	(.17)	(.08)	(.03)	(.03)	
<60 yr	6.4	6.7	7.1	8.1	6.2	6.4
(.03)	(.12)	(.17)	(.10)	(.03)	(.03)	
≥60 yr	7.2	8.5	8.3	9.4	6.8	7.3
(.07)	(.24)	(.65)	(.16)	(.07)	(.07)	

Note: Numbers in parentheses are standard errors.
[a]Not reported because of a large variance in observed data.
Source: Ref. 12.

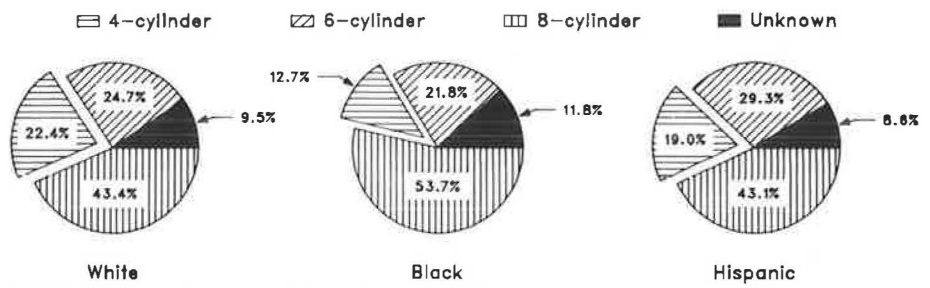

FIGURE 5 Engine size distribution of vehicles in white, black, and Hispanic households, 1983.

driving (e.g., scarce parking, traffic congestion); (b) their older, less reliable vehicles; and (c) a greater prevalence of informal travel arrangements such as loaning of vehicles, the mileage from which is not reflected in the data.

HOUSEHOLD TRAVEL

Total Travel

Black, Hispanic, and poor households travel substantially less than the average U.S. household. Although much of the difference is due to the large numbers of minority and poor households without vehicles, a statistically significant difference remains when the data are summarized for only those households with vehicles (Figure 8). Because miles of travel vary significantly with household income (Figure 9), much of this difference reflects the lower incomes of minority versus white households. However, when income, residence location, householder age, and vehicle ownership are controlled, a clear disparity is evident between black and white low-income single-vehicle households in central cities (Table 2). Again, these differences may be due to (a) older, less reliable vehicles, and limited ability to pay for expensive repairs; (b) local conditions (e.g., parking cost and availability, traffic congestion, transit accessibility), all of which raise the cost or otherwise reduce the attractiveness of private-vehicle use; and (c) greater vehicle loaning among particular population subgroups.

Travel to Work

The attributes of work trips with the greatest relevance to overall minority travel patterns and energy use are their length and spatial characteristics, mode split, and average private-vehicle occupancy. Even when residence location is controlled, minority work trips tend to exhibit distinctive patterns for many of these attributes. Because of space limitations, the following discussion focuses on average trip lengths and mode split. Spatial characteristics and vehicle occupancies are discussed elsewhere *(5)*.

Trip length is characterized in terms of either distance or duration such as travel time. Both provide a useful description of travel patterns, but respondent-reported distance is often subject to considerable error; therefore, duration tends to be a more reliable measure. Duration varies somewhat with income and residence location, but other factors—including mode split, distribution of commuter flows, and size of metropolitan area—are at least as important. As shown in Table 5, suburban work trips tend to be somewhat longer than average and non-SMSA work trips tend to be somewhat shorter. All else being equal, work trips also tend to lengthen with increasing income. However, the difference in mean travel times between whites and blacks, and to a lesser extent between whites and Hispanics, is considerably greater than the variation by either

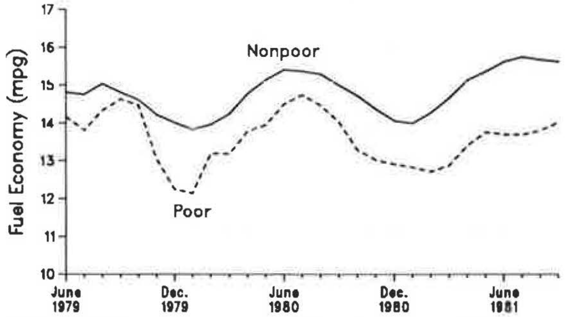

FIGURE 6 Fuel economy of vehicles in white, black, and poor households, June 1979-September 1981.

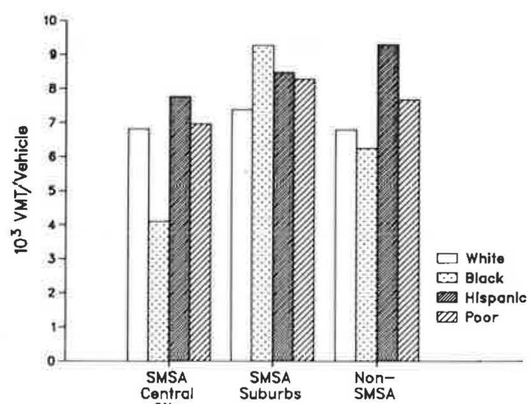

FIGURE 7 Annual vehicle-miles of travel (VMT) for low-income households by residence location and population group, 1977.

income or location. Blacks have significantly longer work trips than whites. When both income and residence location are controlled (see Figure 10), the difference persists, particularly for workers living in metropolitan areas. Among central city residents, only at the highest income level is the mean trip length of black workers approximately equal to that of white workers (14).

About one-half of the variation is explained by differences in mode split. In 1980, the overwhelming majority of white workers (>72 percent) drove alone and only 5 percent used public transportation for their work trips. Most minority workers also drove alone (55 percent of blacks and 60 percent of Hispanics), but as a group they were far more dependent on public transportation (nearly 19 percent of black and 13 percent of Hispanic workers). An additional 25 percent of minority workers used carpools or vanpools, compared with 21 percent of white workers *(14)*.

When the data are controlled for residence location and the

TABLE 4 ANNUAL MILES PER VEHICLE BY HOUSEHOLD CHARACTERISTICS FOR EACH POPULATION GROUP, 1977

Household Characteristic	White	Black	Hispanic	Poor	Nonpoor	All Households
Household Income						
<$7,500	6953	5700	8423	7157	6680	6923
(229)	(374)	(793)	(260)	(300)	(206)	
$7,500-14,999	8824	8965	9792	9207	8865	8894
(267)	(711)	(1004)	(792)	(272)	(256)	
$15,000-24,999	9972	9063	8962	NA	9882	9882
(326)	(964)	(1309)		(313)	(302)	
≥$25,000	10086	10879	[a]	NA	10055	10055
(406)	(1771)			(416)	(393)	
Residence Location						
SMSA Central City	8807	7235	8430	6964	8819	8609
(269)	(421)	(697)	(361)	(265)	(239)	
SMSA Suburbs	9808	12084	8494	8282	9983	9858
(285)	(1024)	(1025)	(532)	(291)	(275)	
Non-SMSA	8718	7150	10173	7675	8880	8684
(257)	(659)	(1829)	(378)	(279)	(246)	
Householder Age						
<60 yr	9774	8907	9006	8790	9798	9696
(202)	(429)	(537)	(345)	(202)	(197)	
≥60 yr	6390	5310	6816	4681	6696	6327
(206)	(581)	(1351)	(354)	(224)	(199)	
All Households	9142	8234	8808	7613	9276	9082
(201)	(367)	(556)	(260)	(206)	(193)	

Note: Numbers in parentheses are standard errors.
[a]Not reported because of too few observations for statistical stability.
Source: Ref. 12.

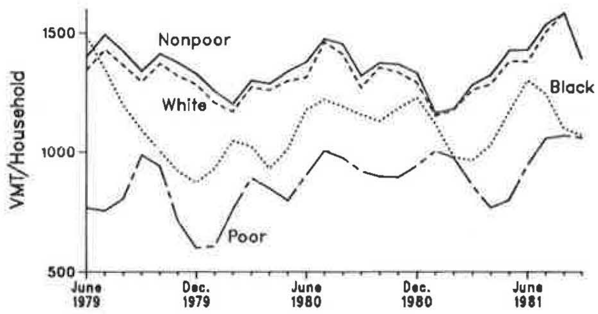

FIGURE 8 Monthly vehicle-miles of travel (VMT) per household, by population group, June 1979-September 1981.

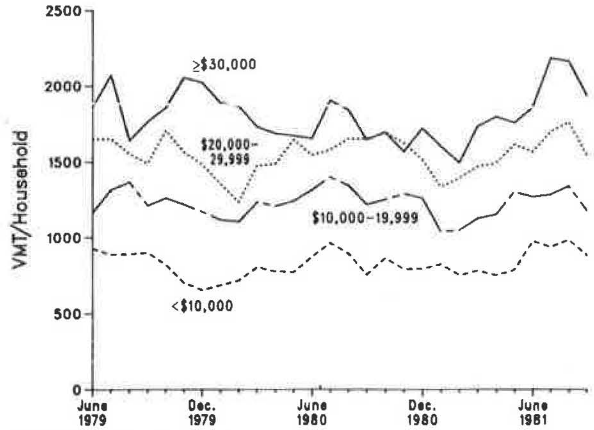

FIGURE 9 Monthly vehicle-miles of travel (VMT) per household by household income category, June 1979-September 1981.

comparison is limited to only those households with vehicles regularly available, the magnitude of mode-split differences among the three groups is reduced. As shown in Table 6, however, minority workers are still significantly more likely to rely on ridesharing and public transportation. Among black workers, ridesharing appears to substitute for public transportation as SMSA size declines. The remaining intergroup differences presumably reflect a series of local factors—including differences in accessibility and level of service of transit and highway systems, spatial characteristics of commuter flows, and vehicle-ownership distributions—that are obscured in national data sets.

FUEL CONSUMPTION AND EXPENDITURES

Household Fuel Consumption

The average vehicle-owning household consumed approximately 88 gal per month of transportation fuel (almost all gasoline) in 1980. Black households consumed slightly less (approximately 84 gal), and poor households consumed considerably less (approximately 68 gal) *(13)*. Figure 11 illustrates these rates, as well as the trend over the 28 months from June 1979 through September 1981. Although white and nonpoor households show a slight downward trend (probably understated because the summer 1979 fuel shortage depressed the initial rates in the time series), consumption rates for black and poor households appear to have risen.

By 1983, black households with vehicles were consuming an annual average of 1,180 gal (98.3 gal per month), compared with 1,211 gal (100.9 gal per month) in Hispanic households and 1,103 gal (91.9 gal per month) in white households. This suggests a slight increase (<5 percent) in the rate for the average white household and a more substantial rise (17 percent) for the average black household. This increase even exceeds the percentage drop in real gasoline price, providing further evidence that vehicle fuel economy in black households improved relatively little over this period, even discounting growth in the average number of vehicles per black household.

Household Fuel Expenditures

In 1983, the average white household spent $1,307 on motor fuel; average black and Hispanic households spent somewhat more—$1,398 and $1,418, respectively—but the differences are not statistically significant*(4)*. Over time, however, evidence suggests a tendency toward elevated expenditure levels in black households. As shown in Table 7, the relative gasoline expenditures of these two groups changed little from 1972 to 1983. For each of these survey years, black households consistently spent 3 percent to 7 percent more on gasoline than did white households.

Between 1972 and 1980, real fuel expenditures rose 44 percent for the average white household, compared with 51 percent for the average black household. Although both dropped by comparable margins between 1980 and 1983, the net increase over the entire 12-year period was 18 percent for white households and 23 percent for black households. Much of this variation is attributable to the income distributions of white and black households. Between 1972 and 1980, fuel expenditures of households in the highest income bracket increased by only 6 percent; between 1980 and 1983 they declined more than 15 percent. On net, these wealthier households reduced their real fuel expenditures by roughly 10 percent between 1972 and 1983. This suggests that the fuel price increases of the 1970s had a greater economic impact on black and low-income households than on white and high-income households.

SUMMARY AND CONCLUSIONS

The first comprehensive investigation of overall travel behavior and transportation fuel use by minority and poor households is documented in this paper. Unlike more narrowly defined research on the subject, this analysis brings together the most relevant information from a variety of national-level data sources. The resulting data base reveals distinctive patterns of household vehicle availability and utilization, travel, and fuel use, and observed differences between population groups can be related to differences in their demographic characteristics and in the attributes of household vehicles owned by or regularly available to them.

TABLE 5 MEAN WORK TRIP LENGTH BY RESIDENCE LOCATION AND HOUSEHOLD INCOME FOR WORKERS IN EACH POPULATION GROUP, 1980

Worker Characteristic[a]	White	Black	Hispanic	Poor[b]	Nonpoor[b]	All Workers
All Workers (mean minutes)	21.1	26.2	23.2	20.5	21.9	21.7
Residence Location[c]						
SMSA Central City	20.8	28.2	24.7	22.4	22.4	22.4
SMSA Suburbs	22.6	25.0	22.7	20.5	23.0	22.8
Non-SMSA	18.3	21.3	18.2	20.4	21.9	21.7
Household Income						
<$10,000	15	22	19	17	17	17
$10,000-19,999	17	23	19	19	18	18
$20,000-29,999	18	25	20	NA	19	19
>$30,000	18	21	19	NA	19	19
All Workers (mean miles)[d]	8.6	9.0	8.5	7.2	8.8	8.6

[a]Excludes persons who work at home. Standard errors of 1980 Census estimates (Ref. 16) are extremely small. Hence, even very small differences are statistically significant. Standard errors are not yet available for Ref. 14.

[b]"Poor" travel time estimates are based on ratio of "poor" to all workers from Ref. 14; "Nonpoor" estimates are computed from "poor" and Ref. 16 values.

[c]1980 SMSA definitions and boundaries.

[d]Not shown by income and location because estimates are less reliable than time estimates and because little variation is apparent in totals.

Sources: Refs. 14 and 16.

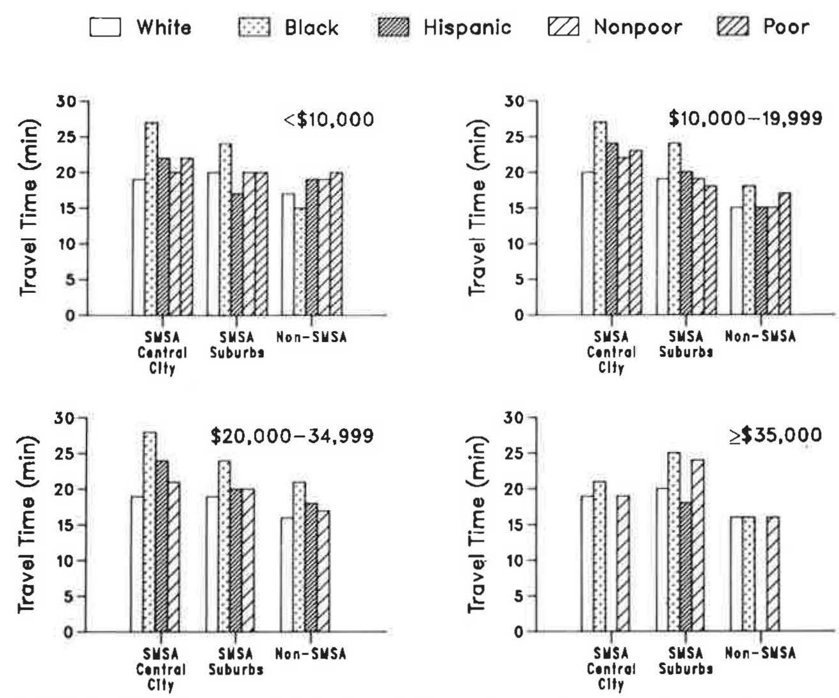

FIGURE 10 Mean work trip travel times, by residence location and household income for each population group, 1980.

TABLE 6 WORK TRIP MODE SHARES BY SMSA SIZE AND VEHICLE AVAILABILITY FOR WHITE, BLACK, AND HISPANIC WORKERS, 1980

SMSA and Mode[a]	Households with Vehicles			All Households		
	White	Black	Hispanic	White	Black	Hispanic
Large SMSA - Central City						
Drive alone	68.1	61.0	56.4	61.7	48.5	43.7
Shared ride	16.3	18.6	26.1	15.6	16.6	23.2
Public transportation	13.3	19.3	16.8	20.2	34.0	32.2
Other	2.3	b	b	2.5	b	b
Large SMSA - Suburbs						
Drive alone	74.0	70.4	65.2	73.2	65.3	62.5
Shared ride	18.5	18.7	29.2	18.5	19.8	29.9
Public transportation	5.5	10.1	4.0	6.2	14.3	6.1
Other	2.0	b	b	2.1	b	b
Medium SMSA						
Drive alone	77.3	70.8	68.7	76.1	63.8	65.3
Shared ride	18.4	22.6	26.9	18.6	23.5	27.2
Public transportation	2.2	6.2	b	3.0	12.1	b
Other	2.1	b	b	2.3	b	b
Small SMSA - Central City						
Drive alone	78.6	62.1	74.0	77.4	56.4	70.8
Shared ride	17.1	26.9	25.4	17.2	28.3	26.7
Public transportation	1.6	b	b	2.2	12.4	b
Other	2.8	b	b			
3.2	b	b				
Small SMSA - Suburbs						
Drive alone	79.1	74.1	82.0	78.8	67.7	80.4
Shared ride	18.5	23.3	14.3	18.5	28.6	16.1
Public transportation	b	b	b	b	b	b
Other	2.0	b	b	1.7	b	b
Non-SMSA						
Drive alone	75.0	61.0	69.4	74.3	55.1	66.8
Shared ride	22.2	36.6	27.8	22.6	40.7	30.1
Public transportation	0.6	b	b	0.7	2.5	b
Other	2.2	b	b	2.3	b	b

Note: In percentages.
[a]Excluding work-at-home and walk trips.
[a]Not reported because of a large variance in observed data.
Source: Ref. 16.

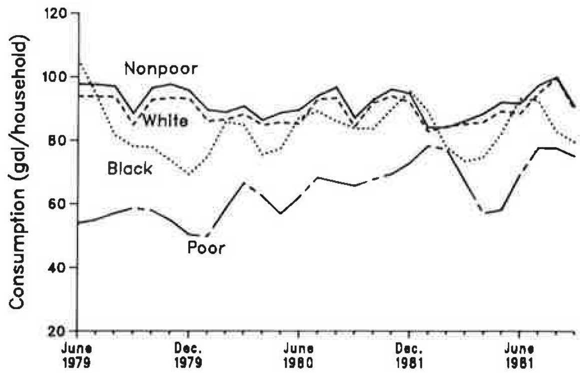

FIGURE 11 Monthly transportation fuel consumption by black, white, poor, and nonpoor households, June 1979-September 1981.

In general, this research confirms the broad relationships between household demographic characteristics (primarily income and residence location) and vehicle use built up over many years of transportation research. Such findings as the greater reliance of blacks on public transportation for their work travel (and, partly as a result, their significantly longer

TABLE 7 ESTIMATED ANNUAL GASOLINE EXPENDITURES, BY HOUSEHOLDS WITH VEHICLES, 1972, 1980, AND 1983

	Survey and Year of Data		
	CES	CES	RTECS
Household Characteristic	1972	1980-81	1983
Population Group			
White	927	1,350	1,071
Black	949	1,438	1,146
Hispanic	NA	NA	1,162
Residence Location			
SMSA Central City	859	NA	957
SMSA Suburbs	987	NA	1,143
Non-SMSA	947	NA	1,126
Household Income[a]			
<$5,000	581	606	698
$5,000-9,999	749	1,028	836
$10,000-14,999	960	1,090	905
$15,000-19,999	1,106	1,366	1,047
>$20,000	1,292	1,730	1,228
All Households	930	1,381	1,080

Note: Estimates in 1980 dollars per household except where noted.
[a]RTECS income ranges are in 1983 dollars. Thus, a small portion of RTECS households may be classified in the next-higher bracket and their expenditures may slightly reduce the average shown for that bracket.
Sources: Ref. 4, 17, 18.

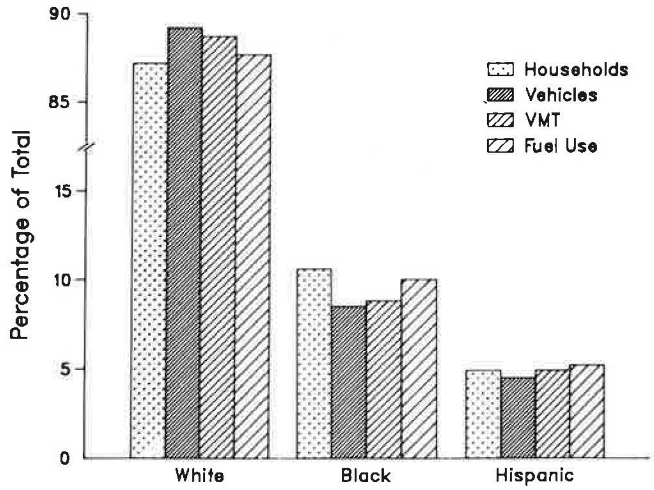

FIGURE 12 Distributions of households, vehicles, vehicle-miles of travel (VMT), and fuel consumption by population group, 1983.

average travel times) also concur with previous research *(8)*. Other findings, however, most notably that significant racial differences exist in vehicle availability and use by low-income households, challenge the conventional wisdom that racial variations arise solely in response to differences in income and housing location. The data suggest that there may be important differences between black and white low-income households, particularly in the yearly fluctuation or dynamics of income, but quite likely in more subtle factors as well. Cross-sectional data sets are not designed to capture these fluctuations, and the data sets are not widely used in local and national-level transportation planning.

Among vehicle-owning households, the average black household travels fewer miles yet consumes more fuel than the average white household. For both blacks and Hispanics, the deficit in vehicle availability is evident in Figure 12. Because Hispanics may be of any race, the shares sum to more than 100 percent. Blacks represented 10.6 percent of all households in 1983, but had only 8.5 percent of all private vehicles. These vehicle-owning households accounted for 8.8 percent of all vehicle miles, but used 10 percent of the transportation fuel consumed by U.S. households. Similarly, Hispanics represented 4.9 percent of all households, held 4.5 percent of all private vehicles, and traveled 4.9 percent of all vehicle-miles, yet consumed 5.2 percent of the transportation fuel used by U.S. households.

The vehicles available to minority and poor households tend to be older and larger, and hence have lower average fuel economy, than the vehicles available to white and nonpoor households. Moreover, evidence suggests that the fuel economy gap has grown over the past several years as affluent households purchased newer and more fuel-efficient models. Quite likely, the fuel economy gains achieved since the late 1970s are only now beginning to reach minority and poor population groups.

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An Investigation into the Use of Market Segmentation Analysis for Transportation Energy Planning

JEFFREY W. TROMBLY

An overview of the results of a recent study on the use of market segmentation analysis in transportation energy planning is presented. Two statewide telephone surveys completed in the State of New York are used to identify groups sharing a similar response to energy price increases and supply short falls. The basis for segmentation was a set of items describing energy conservation actions. Subjects were asked to indicate actions taken over the previous year to save gasoline. These responses were then used to construct matrices of interitem correlations. These matrices were factor analyzed yielding eight common factors. The action factors contained items describing shop travel, nonautomobile mode choice, vehicle replacement, automobile maintenance, moving, nonautomobile work travel, changing leisure activity, and cancelling a vacation. The results yielded a consistent set of factors across survey years that were used to construct factor scores. These scores were used in a cluster analysis algorithm to identify segments sharing a similar response to conservation. A total of eight segments were identified, one segment included subjects with a high willingness to conserve gasoline and were characterized by high automobile ownership, high income, and upstate location. Another large segment had a very low willingness to conserve and contained subjects with low automobile ownership, small household size, and downstate location. The results of this study can be used to design programs and policies to meet future planning needs in the event of limited gasoline availability.

The history of the last decade has included a large-scale response on the part of government, the private sector, households, and individuals to rapidly increasing energy prices and supply shortfalls. A major emphasis has been placed on decreasing the vulnerability of society to imported oil. In the transportation sector this has meant the development of various legislative and administrative initiatives to help contribute to a reduction of growth in energy requirements. In particular, a strong federal role was developed that encouraged other levels of government to participate in a transportation energy planning process.

Transportation energy policy has been formulated to address the mobility needs of a broad spectrum of consumers. Limited attempts have been made to seek out selected target groups in the general population to assess the ability and willingness of the individual consumer to participate in energy-related conservation programs.

Travel demand reflects a complex set of private decisions. Experience shows that consumers respond in various ways to energy price increases and supply shortages. The individual interacts with other members of a household in defining activity needs. These needs can be broken down into necessary activities (e.g., work, food shopping) and discretionary activities (e.g., personal business, nonfood shopping, recreation). However, the spatial-temporal choices associated with these activities are limited by constraints related to the household (e.g., income, automobile ownership, individual roles in the household) and constraints related to the transportation system (e.g., travel time and cost, energy supply and price).

The individual and the household must continually balance activity needs and desires with system constraints to arrive at an optimum combination of travel-related decisions. For example, a household characterized by a certain level of automobile ownership, household composition, and geographic location may adapt to increasing gasoline prices by (a) reducing the use of the automobile, (b) replacing an automobile with a more fuel-efficient model, (c) linking work and nonwork trips, or (d) moving the location of the household to reduce work-trip length.

The result of a recent study that incorporates the concepts of market segmentation analysis in transportation energy planning *(1)* is summarized here. This analysis approach is motivated by a desire to understand the nature of energy conservation behavior on a disaggregate level so that scarce planning resources can be applied in a manner consistent with target segment needs.

In order to implement a complete market segmentation analysis it is necessary to establish the existence of subgroups in the general population under study. In addition, it must be shown that knowledge of such segments can be exploited to better achieve organizational objectives. Finally, resources must be expended in a manner that is consistent with satisfying the needs of target segments.

Therefore the market segmentation strategy consists of the following steps: (a) selection of a segmentation basis, (b) development of segment profiles, (c) examining the response of segments to selected policies and programs, and (d) selection of target segments to be pursued by the organization.

STUDY DESIGN

The essence of the market segmentation process consists of identifying unique attributes shared by a common group that are related directly or indirectly to some behavior of interest. In this study, the behaviors under investigation are those actions taken by individuals to conserve transportation-related energy. In October 1979, and again in October 1980, separate random

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samples of New York State households were asked to endorse, from a list of 18, the actions undertaken to conserve gasoline since January of those respective years. Subject responses were coded either 0 for no action or 1 for action. In addition, selected socioeconomic variables were collected to describe survey respondents.

In earlier work, Neveu and Hartgen *(2)*, and Neveu *(3)* centered these data on examining cross tabulations of actions with selected independent variables to identify the relationship between individual characteristics and action endorsement. In addition, the survey results were applied to estimate energy savings. In this current effort, a subject's response set is considered a reflection of an underlying willingness and ability to conserve gasoline and serves as the basis for market segmentation.

Market segments are developed from a three-step process. First, in order to reduce the number of measures used to describe the conservation construct, correlation matrices consisting of product moment correlation coefficients between each action are factor analyzed using principal factor analysis. The results of this effort include the estimation of factor scores for each subject. Next, factor scores for these subjects are grouped using a cluster analysis algorithm. The results of this analysis serve as the method for identification of segments.

Finally, once each subject is assigned to a particular segment, group membership is cross-tabulated with each energy conservation action in order to confirm the relationship between groups and actions. This process also represents a method to validate cluster analysis results by establishing the connection between factor scores and energy conservation actions.

The development of market segments leads to an investigation of group profiles. Profiles are developed for each segment by cross classifying group membership with selected socioeconomic characteristics. After profiles are identified, target segments are matched with selected programs and policies consistent with the characteristics of the conservation behaviors of these groups. The final results suggest a level of consistency over the surveys, both in terms of segment profiles and behavior.

SURVEY RESULTS

The data base used in this research was collected as part of the Crossley Empire State poll. The poll was conducted four times per year in 1979 and 1980 and was designed to allow several organizations in the New York State government the opportunity to conduct a shared-cost telephone survey. In October 1979 a statewide sample of 1,520 adults was collected, and in October 1980 a separate group of 1,560 adults was interviewed. The samples compared favorably to characteristics of the statewide population as given in Table 1.

The results of these surveys for the energy action items is given in Table 2 and suggest the importance of actions requiring changes in shopping-related travel. In particular, combining trips or trip chaining, shopping closer to home, and making fewer shop trips are among the items with the highest proportion of endorsement. In addition, driving slower, shopping on the way home from work, and tuning a vehicle played a large role. Except for vacation-related actions and purchasing fuel-efficient automobiles, remaining actions were endorsed only at a very low proportion.

TABLE 1 SUMMARY OF SURVEY RESULTS FOR SELECTED INDEPENDENT VARIABLES

VARIABLE	CATEGORY	1980 CENSUS	1979 SURVEY	1980 SURVEY
Area in State State	° Downstate Urban	0.607	0.601	0.548
	° Upstate Urban	0.180	0.221	0.262
	° Other	0.213	0.178	0.190
Age	° 18-34 Years	0.357	0.397	0.363
	° 35-64 Years	0.417	0.482	0.454
	° Over 65 Years	0.156	0.115	0.170
	° Missing		0.006	0.013
Sex	° Male	0.462	0.495	0.469
	° Female	0.538	0.505	0.531
Marital Status	° Married	0.522	0.618	0.576
	° Single	0.306	0.236	0.249
	° Widowed, Divorced Separated	0.172	0.141	0.165
	° Missing		0.005	0.010
Household Size	° 1 - 2	0.550	0.439	0.503
	° 3 - 4	0.313	0.378	0.343
	° 5 or More	0.137	0.176	0.137
	° Missing		0.007	0.017
Annual Income	° Less than $10K	0.304	0.156	0.503
	° $10K to $25 K	0.402	0.445	0.343
	° Over $25K	0.294	0.261	0.137
	° Missing		0.138	0.017

TABLE 2 SUMMARY OF SURVEY RESULTS FOR ENERGY CONSERVATION ACTIONS

ACTION	DESCRIPTION	1979	1980
1	Drive more slowly than before	0.418	0.428
2	Carpool to work	0.139	0.133
3	Take bus or subway to work	0.120	0.135
4	Walk or bike to work	0.083	0.108
5	Have car tuned more often	0.372	0.256
6	Move closer to work	0.025	0.031
7	Get job closer to home	0.052	0.043
8	Shop on the way home from work	0.252	0.301
9	Make fewer shopping trips	0.350	0.532
10	Combine shopping and other non-work	0.468	0.537
11	Shop closer to home	0.410	0.470
12	Eliminate use of recreation vehicles	0.093	0.117
13	Take vacation closer to home	0.170	0.187
14	Cancel a vacation trip	0.156	0.118
15	Use train, bus or plane for vacation trips	0.159	0.207
16	Replace a car with a more fuel efficient one	0.153	0.173
17	Sell car (don't replace)	0.084	0.051
18	Take bus or subway more often for non-work trips	0.174	0.150

FACTOR ANALYSIS AND CLUSTER ANALYSIS RESULTS

Matrices consisting of the set of the product moment correlation coefficients between action item responses were developed and factor analyzed to (a) help identify the common factors describing the relationship between actions, and (b) reduce the dimensionality of the action response data for use in cluster analysis.

The principal factor solution, developed using the set of squared multiple correlations as commonality estimates, resulted in the identification of eight common factors for both survey year data sets. This interpretation is confirmed by Table 3, in which the final eigenvalues and proportion total common variance explained for the 1979 and 1980 data are also given. The eight factors explain nearly 97 percent of the total variance.

In order to develop a better understanding of the relationship between factors and variables, the matrices of factor loadings were rotated. This process does not change the amount of variance explained by the solution, but enhances the interpretation of the results. In this case, an oblique rotation of the common factors was performed using the criterion developed by Jenrich and Sampson *(4)*. The results of this effort are summarized in Table 4 in which the relationship between factors across survey years is shown. The important concept in this comparison is not the specific factor number, but the content of items comprising a factor. This suggests the presence of eight factors or dimensions describing energy conservation behavior.

The first factor contains actions related to shopping behavior. The second set of actions contains items related to nonautomobile mode choice. The third factor consists of items dealing with mode choice. The fourth contains items dealing with maintenance of an automobile. The sixth factor contains moving behavior actions. The seventh factor consists of actions related to change in leisure activity, and the eighth factor contains an item concerned with dropping a vacation.

The results of this factor analysis lead to several observtions. First, it appears that emerging factors consist of dimensions describing actions that can be implemented easily such as automobile maintenance or require a disruptive change in behavior such as moving.

A second observation concerns the factor consisting of items related to nonautomobile mode choice. The content of these items suggests that change of travel mode is an important element considered in all travel purposes. It is interesting to note that the factor consisting of items related specifically to work travel comprises a separate dimension.

The factor dealing with the choice of the nonautomobile

TABLE 3 EIGENVALUE CONFIGURATIONS

	1979		1980	
FACTOR	EIGENVALUE	CUMULATIVE PROPORTION OF TOTAL VARIANCE	EIGENVALUE	CUMULATIVE PROPORTION OF TOTAL VARIANCE
1	2.9664	0.4848	3.2162	0.5243
2	0.9596	0.6416	0.8305	0.6471
3	0.7386	0.7623	0.6130	0.7451
4	0.4348	0.8334	0.4391	0.8153
5	0.2518	0.8745	0.3195	0.8664
6	0.2422	0.9141	0.2476	0.9060
7	0.1872	0.9447	0.2171	0.9407
8	0.1368	0.9671	0.1552	0.9655
9	0.0894		0.0809	
10	0.0601		0.0612	
11	0.0447		0.0451	
12	0.0074		0.0264	
13	-0.0023		0.0019	
14	-0.0110		0.0062	
15	-0.0134		-0.0167	
16	-0.0424		-0.0507	
17	-0.0572		-0.0691	
18	-0.0798		-0.0879	

TABLE 4 ACTIONS COMPRISING FACTORS

Factor by Year			
1979	1980	Actions	Factor Name
1	1	Shop less frequently Combine shop and other Shop closer to home	Shop travel
2	2	Bus or subway to work Bus or subway for nonwork Use train, bus, plane for vacation	Nonautomobile mode choice
3	7	Buy fuel-efficient car Sell car	Vehicle replacement
4	6	Drive slower Tune car	Maintain automobile
5	3	Move closer to work Job closer to home	Move
6	5	Carpool to work Walk or bike to work Shop on way home from work	Nonautomobile work travel
7	4	Eliminate use of recreational vehicle Vacation closer to home	Change leisure
8	8	Cancel vacation	Drop vacation

TABLE 5 DEGREE OF FACTORIAL SIMILARITY CALCULATED FROM ROTATED LOADING MATRICES, 1979 AND 1980

1979 Factor	1980 Factor 1	2	3	4	5	6	7	8
1	0.961[a]	0.049	0.066	0.086	0.238	0.154	0.033	0.137
2	0.040	0.965[a]	0.027	0.010	0.129	−0.052	0.088	−0.004
3	0.044	−0.052	0.025	0.163	0.153	0.180	0.861[a]	−0.116
4	0.312	0.063	0.121	0.282	0.300	0.843[a]	0.086	−0.098
5	0.054	0.018	0.952[a]	0.106	0.070	−0.076	0.075	−0.082
6	0.120	0.083	0.030	0.257	0.795[a]	0.000	−0.030	−0.262
7	0.077	0.001	0.129	0.825[a]	−0.014	0.122	0.078	0.199
8	0.179	0.084	0.170	0.525	0.209	0.023	0.270	0.405[a]

[a]Values are factors with the highest similarity.

mode for work travel also contains an item dealing with shopping on the way home from work. This type of behavior is inconsistent with carpooling for work travel because these types of side trips often disrupt a carpool relationship. This observation indicates that these surveys measure opinions as well as behavior because there is evidence of a factor consisting of contradictory behaviors. Perhaps the subject is responding, in part, based on an attitude or opinion that reflects an agreement with the statement that shopping on the way home from work is a good way to save transportation energy.

The outline of the factor analysis results thus far has included a subjective interpretation of the rotated factor results. An additional step to confirm these results included pair-wise comparison of each set of factor loadings throughout calculation of root mean square deviation between factor loadings and calculation of the degree of factor similarity, Harman (*5*, p. 346). The results of these efforts are given in Tables 5 and 6.

The values of factor similarity that have the highest positive value for each factor pair are outlined in Table 5. Highlighted in Table 6 are the smallest values of the root mean square deviation for each set of factor pairs. Generally, the earlier subjective interpretations are supported in Tables 5 and 6.

The factor analysis results suggests that different survey samples interpret the content of an item in a similar fashion. In addition, the outcome uncovers some counter intuitive patterns that cannot be identified without a factor analysis evaluation.

Following the determination of the common action factors, a set of factor scores were then developed to serve as input to a cluster analysis algorithm. For purposes of this research, K-means cluster analysis was applied *(6)*. This technique partitions the set of measures into a prespecified number of groups based on distances between cluster centroids. Several group sizes were specified and evaluated based on minimizing within-group dispersion. Table 7 summarizes the results of this effort for a combination of group sizes. This table suggests that within-group dispersion decreases with each increase in the number of groups. It appears that the greatest rate of change of within-group variation occurs at the eight-group solution. Note that it requires the addition of 12 more groups beyond the eight-group solution to reduce the within-group variation an amount similar in size to the drop occurring between the five-group and eight-group specification.

Based on this observation, an eight-group solution was selected for further analysis. Although somewhat subjective, this interpretation represents a reasonable application of the principles of cluster analysis that results in a manageable number of groups for additional analysis.

ENERGY CONSERVATION ACTIONS

Cross classification of group membership with energy action item responses followed the cluster analysis. This was under-

TABLE 6 ROOT MEAN SQUARE DEVIATION CALCULATED FROM ROTATED LOADING MATRICES

1979 Factor	1980 Factor 1	2	3	4	5	6	7	8
1	0.006[a]	0.111	0.097	0.092	0.072	0.076	0.082	0.069
2	0.125	0.003[a]	0.094	0.092	0.074	0.085	0.072	0.070
3	0.113	0.106	0.080	0.071	0.065	0.060	0.015[a]	0.067
4	0.077	0.084	0.066	0.051	0.044	0.010[a]	0.051	0.052
5	0.094	0.077	0.005[a]	0.055	0.049	0.053	0.043	0.041
6	0.084	0.067	0.057	0.042	0.013[a]	0.043	0.041	0.040
7	0.085	0.070	0.050	0.012[a]	0.046	0.034	0.035	0.035
8	0.077	0.063	0.047	0.027	0.034	0.038	0.026	0.017[a]

[a]Values are factors with the lowest root mean square deviation.

TABLE 7 SUMMARY OF TOTAL WITHIN GROUP VARIATION FOR SELECTED GROUP NUMBERS

NUMBER OF GROUPS	TOTAL WITHIN GROUP VARIATION 1979	1980
5	2,710	2,641
8	2,088	2,109
10	1,916	1,991
15	1,632	1,583
20	1,459	1,372

taken to develop a better understanding of the relationship between action response and group membership within survey years and between survey years. The results of this effort are given in Table 8, in which the relationship between group membership and action factors is shown. In addition, the proportion of subjects in each group is summarized. A measure of the ability and willingness of segment members to undertake actions comprising a factor is given. These indicants are found by summing the individual level of endorsement for each item in a factor and then dividing this quantity by the number of items comprising a factor.

A summary of the similarities between market segments over the survey years is also attempted by suggesting that the eight groups identified earlier can be matched, in a reasonable manner, by comparing the level of endorsement exhibited by each group for various action items. This interpretation leads to the identification of eight overall market segments labeled A to H.

The names of the conservation actions endorsed by these eight overall groups are given in Table 9. Note that, for the most part, all groups have undertaken actions related to shopping travel and automobile use and maintenance. In addition Segments B and C suggest a willingness to implement non-automobile mode choice decision. Vehicle replacement appears to be an option for overall Segment A along with moving place of work or residence.

Briefly, a reasonable degree of stability of group energy conservation behavior has been established over the survey years. For the most part, segments have endorsed a variety of

TABLE 8 CROSS CLASSIFICATION OF SEGMENTS AND FACTORS

Factor 1979	1980	Market Segments[a] and Groups[b] A 1979 5	A 1980 1	B 1979 2	B 1980 2	C 1979 3	C 1980 3	D 1979 1	D 1980 4
4	6	0.59	0.69	0.33	0.19	1.73	1 71	1 77	0.72
1	1	9.78	0.86	0.27	0.41	0.69	0.89	0.84	0.89
6	5	0.35	0.42	0.15	0.13	0.57	0.40	0.41	0.32
7	4	0.50	0.41	0.07	0.008	0.39	9.38	0.51	.064
8	8	0.32	0.27	0.17	0.04	0.49	0.38	0.37	0.48
3	7	0.49	0.30	0.03	0.31	0.31	0.21	0.71	0.43
5	3	0.68	0.63	0.02	0.01	0.14	0.000	0.07	0.00
2	2	0.23	0.35	0.53	0.53	0.85	0.73	0.16	0.10
Group size		37	78	139	111	70	103	62	104
Proportion		0.02	0.05	0.09	0.07	0.05	0.07	0.04	0.07
Average no. of actions		9.0	9.2	3.9	3.8	9.9	9.0	8.7	8.0

Factor 1979	1980	E 1979 4	E 1980 5	F 1979 8	F 1980 6	G 1979 7	G 1980 7	H 1979 6	H 1980 8
4	6	0.73	0.16	0.73	0.66	0.09	0.07	0.41	0.50
1	1	0.49	0.42	0.83	0.84	0.04	0.14	0.51	0.73
6	5	0.15	0.31	0.30	.050	0.03	0.03	0.11	0.06
7	4	0.13	0.06	0.29	0.21	0.02	0.02	0.07	0.12
8	8	0.16	0.01	0.30	0.17	0.03	0.03	0.11	0.09
3	7	0.50	0.09	0.01	0.17	0.02	0.02	0.00	0.09
5	3	0.02	0.04	0.03	0.00	0.001	0.00	0.01	0.01
2	2	0.07	0.21	0.13	0.14	0.04	0.03	0.02	0.05
Group size		124	155	255	158	518	530	315	321
Proportion		0.08	0.10	0.17	0.10	0.34	0.34	0.21	0.21
Average no. of actions		5.0	3.5	6.1	6.7	0.6	0.76	3.0	4.0

Note: Cell values calculated from the average rate of endorsement for items comprising a factor.

[a]Designated by letters.
[b]Designated by numbers.

TABLE 9 SUMMARY OF ACTION ENDORSEMENT

Segment	Description	Conservation Emphasis
A	Young upstate family	Automobile use and maintenance, shop travel, nonautomobile work travel, vacation and leisure, vehicle replacement, moving
B	Mature downstate family	Automobile use and maintenance, nonautomobile work travel, nonautomobile mode choice
C	Upper-income downstate family	Automobile use and maintenance, shop travel, nonautomobile work travel, vacation and leisure, moving, nonautomobile mode choice
D	Moderate-income upstate family	Automobile use and maintenance, shop travel, nonautomobile work travel, vacation and leisure, vehicle replacement
E	Unclear	Automobile use and maintenance, shop travel, vehicle replacement
F	Moderate income upstate compile	Automobile use and maintenance, shop travel, nonautomobile work travel
G	Nonconsumer	Low endorsement proportions for all actions
H	Upper-income upstate family	Automobile use and maintenance, shop travel

actions. However, more than 30 percent of each sample appear to have a very low willingness to undertake conservation actions. The following section describes the socioeconomic characteristics of these segments so that effective conservation policies can be suggested to meet the needs of such groups in the event of any future energy shortage.

SEGMENT PROFILES

In addition to examining the average action endorsement proportions, a set of figures describing the characteristics of the eight overall segments have been prepared. These figures have been developed from the results of cross classifying group membership with various socioeconomic characteristics.

A major inconsistency in the characteristics of Group E was observed at this point. Additional analysis is required before drawing any conclusions about this group. Therefore, further discussion concentrates on the seven remaining segments.

The results for overall Segments A, F, D, and H are shown in Figure 1, and the results for overall Segments C, B, and G are shown in Figure 2. In general terms, it is suggested that the segments can first be described by area location with the results for segments from the upstate urban or other areas shown in Figure 1, and groups from the downstate urban area shown in Figure 2.

In Figure 1 the four upstate urban or other area segments are characterized by high vehicle ownership, single-family housing and high school or college education. Next, age becomes an important element in defining a segment. After this, groups are distinguished by income levels, and family or household size.

The relationship between group characteristics and actions for downstate urban area segments is outlined in Figure 2. As shown, all groups are characterized by the young to middle aged, multi-family housing, and low to moderate household size. Next, income and automobile ownership vehicles are used to define segments. Finally, the three segments are characterized by different levels of educational attainment.

Briefly, the results suggest the importance of geographic location in understanding the nature of energy conservation response. Downstate urban subjects tend to endorse a lower number of actions and tend to concentrate on transit options to maintain mobility. The upstate urban or other area subjects are more willing to endorse a higher number of actions than the downstate urban area segments. Income, automobile ownership, and education are also related to action endorsement

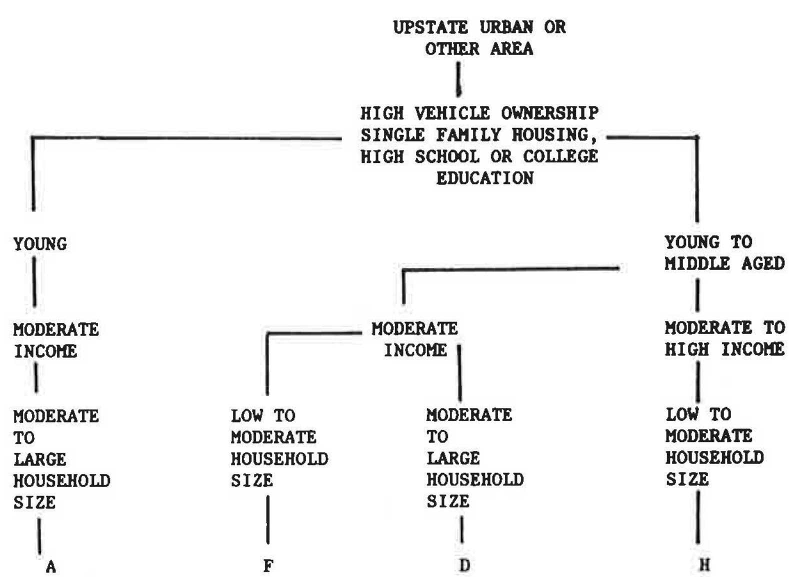

FIGURE 1 Summary of profiles for upstate market segments.

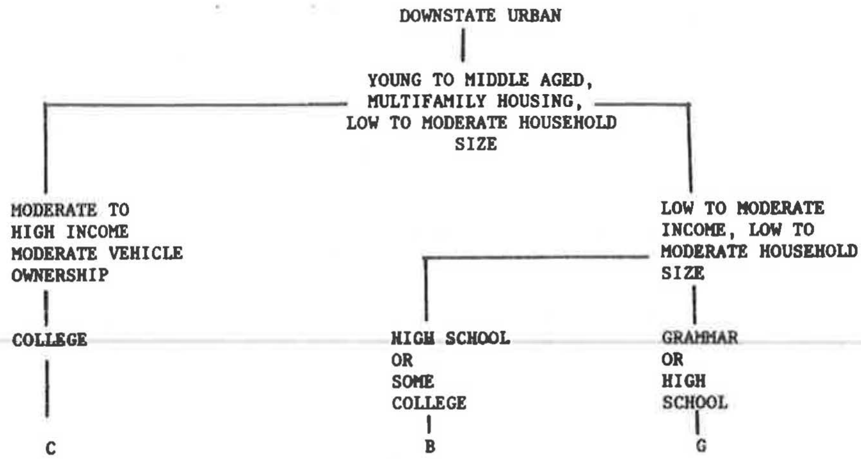

FIGURE 2 Summary of profiles for downstate market segments.

levels. In the upstate area age, income, and household size are important variables contributing to an understanding of conservation action endorsement.

APPLICATIONS

Now that a consistent set of segments has been defined, it is necessary to describe a set of feasible conservation policies and programs to meet the needs of these groups. Based on the analysis results, there are two recommended sets of programs: informational campaigns and improved service provisions such as expansion of public transportation or carpool matching.

The set of informational campaigns is designed to help affirm certain behaviors and raise the consciousness of potential participants in such conservation actions. This includes providing newspaper, radio, or television messages concerning the advantages of planning daily travel so that trips can be consolidated or eliminated. Other messages concerning automobile use and maintenance can be described and implemented to service the needs of target segments. Fuel availability literature can be distributed through the media to ease concern about future availability of gasoline in vacation or resort areas. One additional example concerns moving behavior and may consist of campaigns targeted at segments able and willing to change their place of residence. As a result of this research, seven target markets that may benefit from these programs have been identified. In the event of future energy shortages this information may be used to reach segments in a cost-effective manner.

The second general program area consists of improvement of selective transportation-related services that include expanding bus, train, or plane service for vacation travel or improving local transit service. In addition, carpool matching and promotional programs can be targeted at selected segments in order to use planning funds in an effective manner.

A series of recommended programs for target market segments is outlined in Table 10. Note that most groups are targeted for some type of informational campaign. Improved services are suggested for a selected number of segments.

TABLE 10 RECOMMENDED PROGRAMS DEVELOPED FROM MARKET SEGMENTATION ANALYSIS

	SEGMENT							
	A	B	C	D	E	F	G	H
RECOMMENDED PROGRAMS								
INFORMATIONAL CAMPAIGNS								
° Trip Planning	o		o	o	o	o		o
° Fuel Availability	o							
° Driving Techniques and Maintenance	o	o	o	o	o	o		o
° Housing Availability	o							
SERVICES								
° Carpool Matching	o	o	o		o			
° Improved Public Transit		o	o					
° Improved Plane, Bus, Train Service for Vacation		o	o					

CONCLUSIONS

These results can be used to guide future energy policy making in the event of gasoline price increases or supply shortfalls. Specifically, the results concerning target group respondent segments can be used to implement a set of informational strategies and service improvement programs to effectively meet the needs of various groups. For example, the target markets identified in this study can provide an indication of the types of planning programs or policies to implement. Furthermore, the results can be used to match programs and specific segments. In this manner, informational campaigns and service improvements can be concentrated in areas with the greatest need.

In addition to suggesting potential conservation strategies these results can be used as a data base for increased understanding of the stability of market segments over time. A similar analysis may now be pursued through the use of another statewide telephone survey to conduct further analysis of a similar nature. If the results of this new study are consistent with these conclusions, then additional information concerning the dynamics of conservation opinion and behavior can be collected.

These results represent an example of the use of market segmentation that can be reviewed by analysts interested in undertaking similar studies. For example, researchers in other states may pursue a similar analysis to identify target segments using data collected in the same time period. Results that emerge can be compared to identify any consistencies or differences.

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