Mental Maps and the Refueling Behavior of Vehicle Drivers

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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.

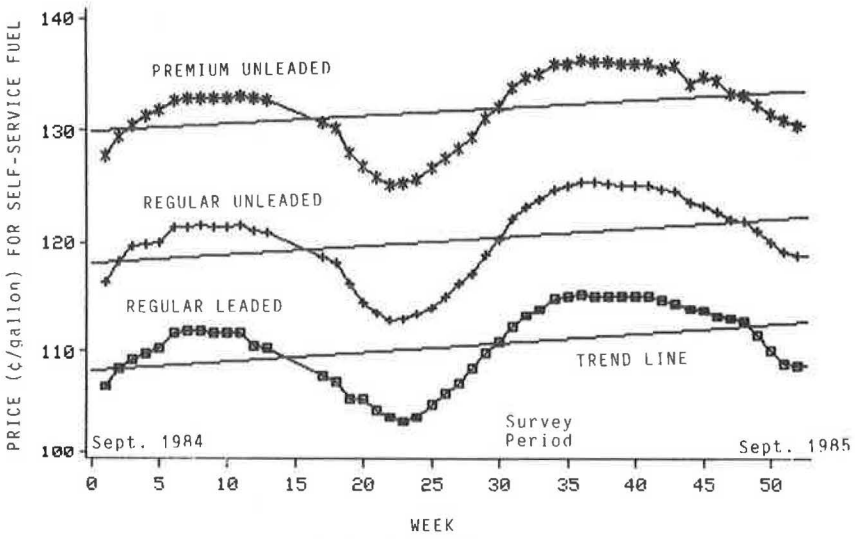

FIGURE 1 Weekly average fuel prices in Davis.

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

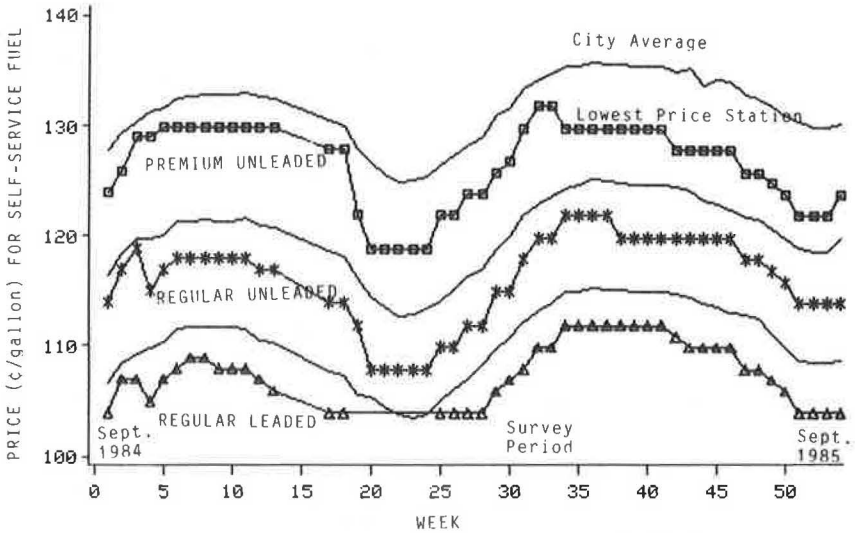

FIGURE 2 Fuel prices trends at the lowest price station in Davis.

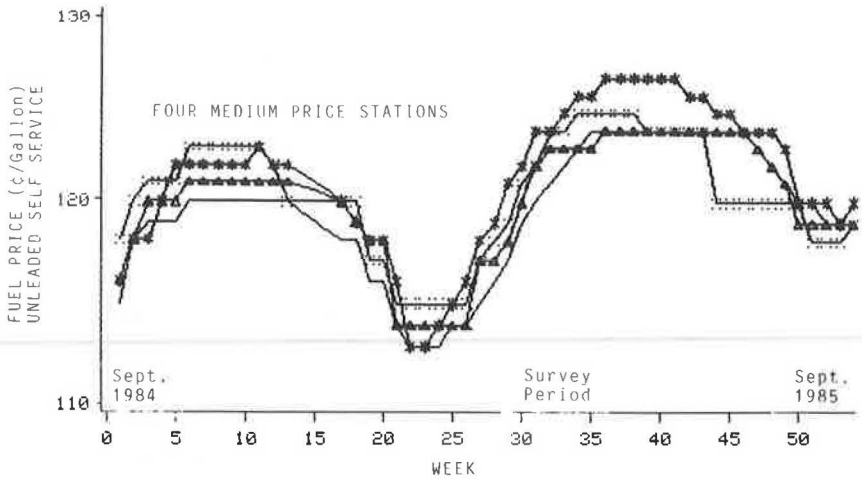

FIGURE 3 Fuel price trends at four medium price stations.

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

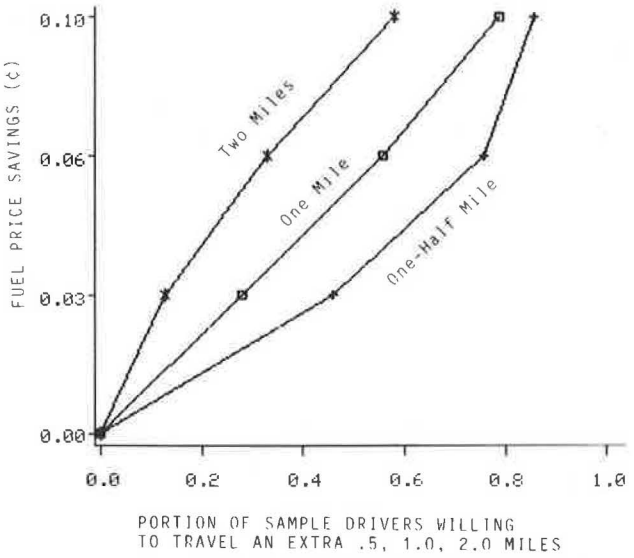

FIGURE 4 Attitudes toward extra travel for fuel price savings.

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

Price Savings ($)	0.5 mi Savings ($)[a]	0.5 mi Driver Willingness (%)[b]	1 mi Savings ($)[a]	1 mi Driver Willingness (%)[b]	2 mi Savings ($)[a]	2 mi 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.

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.

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