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REFUELING BEHAVIOR OF AUTOMOBILE DRIVERS

RYUICHI KITAMURA AND DANIEL SPERLING
Department of Civil Engineering, and Division of Environmental Studies, University of California at Davis, Davis, California 95616, U.S.A.

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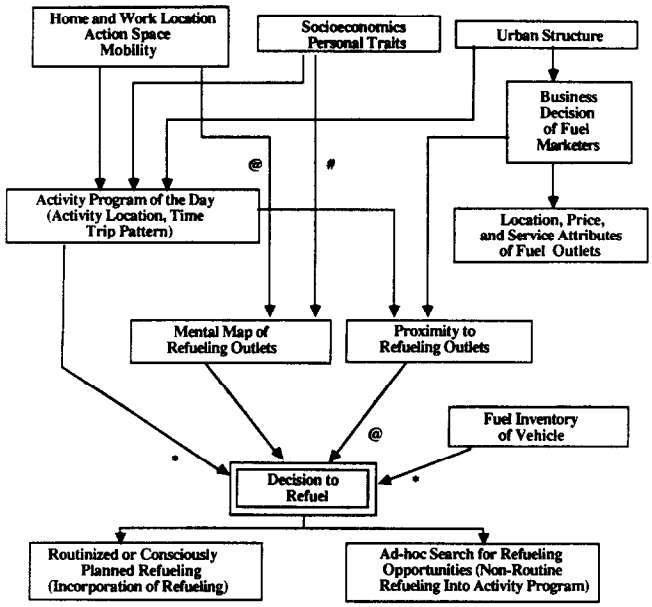
Abstract—This paper presents a descriptive and explanatory analysis of refuelling behavior of gasoline-car drivers. The relationship between drivers' attributes and their refueling behavior is examined using the results of driver surveys conducted at several refueling outlets in northern California. The objectives of the analysis are to identify spatial and temporal characteristics of refueling behavior, and to evaluate the variations in refueling behavior across driver population segments. The results show that refueling behavior is only weakly correlated with demographic and socioeconomic descriptors of the driver. On the other hand, variables representing car ownership and utilization are strongly associated with refueling behavior.

1. INTRODUCTION

Refueling activities have been virtualy ignored in previous empirical and theoretical studies of travel behavior and fuel use. Neither conventional origin-destination surveys nor more recent disaggregate travel surveys have included refueling as a separate trip purpose category (e.g. Memmot, 1963; Charles River Associates, 1977). When refueling was the sole purpose of a trip, it was perhaps classified in the coding process as either a shopping or personal business trip. In the more common case when it was part of a multipurpose trip, the refueling stop was presumably ignored and the two trip legs before and after refueling were treated as one continuous trip. The existing travel behavior literature addresses refueling only in the analysis on contingency queueing behavior at service stations under restricted gasoline supply (e.g. Prins *et al.*, 1980; Horowitz, 1982). The only known energy consumption survey that collected data on refueling was conducted recently for the U.S. Energy Information Administration. It collected data on the date, odometer reading, and fuel quantity purchased for each refueling stop—data which are useful for fuel consumption and vehicle efficiency analyses, but not for analysis of refueling behavior. Cavalier treatment of refueling is presumably due to a perception that refueling activities have insignificant impact on travel and vehicle-purchase decisions.

It may be true that fuel availability has a minor impact on travel behavior and vehicle-purchase decision when fuel is available at a large number of locations. It is not true when fuel availability is limited and when there is only a sparse network of fuel outlets. This condition of limited fuel availability would exist during the early stages of a transition to nonpetroleum energy sources (e.g. methanol, ethanol, compressed and liquefied hydrocarbon gases, hydrogen, and batteries). The absence or sparseness of fuel outlets is widely acknowledged to be one of the major barriers impeding the introduction of new fuels (Koyama *et al.* 1984; Jet Propulsion Laboratory, 1983; Sperling, 1984; U.S. Congress, 1984). The problem has been characterized in terms of the chicken-or-egg allegory. Fuel marketers are unwilling to invest in a distribution network for a new fuel until there is a reasonable likelihood of a sufficiently large market developing, while automakers are unwilling to invest in the manufacture and marketing of multi-fuel or nonpetroleum vehicles if there is no guarantee that plentiful amounts of that nonpetroleum fuel will be readily available. And, of course, the consumer is hesitant to purchase a nonpetroleum vehicle unless assured of plentiful fuel over time and across geographical space. An understanding of refueling behavior provides the knowledge to determine the effect of different network configurations of retail fuel outlets on the decision to purchase a nonpetroleum vehicle and thereby provides an informed basis for dealing with the chicken-or-egg problem.

The decision of when and where to refuel is related to many factors. As suggested in Fig. 1, the driver's refueling decision is related to the driver's activity program, quantity of fuel remaining in the tank, location of fuel outlets, and with the price and service attributes associated with fuel outlets. It is also hypothesized in Fig. 1 that refueling is performed in two different contexts. In many instances refueling may be a routine task performed at a frequently visited outlet in the vicinity of home or workplace. In this case the decision of where to refuel has already been made through the processes of information acquisition, experimentation, and habit formation. Such a visit may be well coordinated with other out-of-home activities the driver is performing such that refueling does not create the needs for an additional trip. In other cases, the driver is exposed either sequentially or simultaneously to a set of more



* Hypothetical relationship addressed in this paper
@ Addressed indirectly in this paper
\# Addressed in Digemans, et al. (1986).

Fig. 1. Schematic representation of the driver's refueling decision

or less unknown refueling opportunities and is making the choice spontaneously on the basis of price, amenity, or brand name. Understanding the contextual variation and determining the relative frequency of routine and nonroutine refueling is an important task toward evaluating the relationship between a limited distribution network and the willingness to purchase a nongasoline vehicle.

In addition to this contextual variation, there exists variation in drivers' responses to refueling opportunities, i.e. each driver given the same conditions and choices will not respond the same. Individuals value time and fuel station service attributes differently. They also have varying levels of accuracy in their mental maps of where outlets are located and of the associated attributes of fuel price and service offered. Because of the resulting heterogeneity in refueling behavior across drivers, it is important to be able to predict behavioral differences, based perhaps on socioeconomic attributes, mobility characteristics, vehicle types, or attitudes and perceptions. This paper investigates this variation in refueling behavior.

In order to establish an information source to identify the characteristics of refueling behavior, a survey of drivers was conducted at selected retail gasoline fuel outlets in northern California from December 1983 through February 1984. In a previous paper, we explained attitudinal factors related to refueling and compared responses from this survey of gasoline-car drivers to those from another smaller survey of diesel car drivers (Sperling and Kitamura, 1986). One major finding was that socioeconomic attributes of drivers are not significantly associated with attitudes toward refueling nor toward adoption (i.e. purchase) of new types of fuels and vehicles. We also found evidence suggesting that although drivers are sensitive to fuel availability, they tend to value the time inconvenience in accessing fuel outlets in an economically rational manner. In another analysis (Dingemans *et al.*, 1986), we demonstrated that drivers' mental map knowledge of refueling opportunities is not associated with socioeconomic and demographic attributes of the driver.

The present paper presents a descriptive and explanatory analysis of refueling behavior of gasoline-car drivers. We examine in particular the spatial characteristics of refueling behavior and analyze the relationship between drivers' attributes and their refueling behavior. The objectives of the paper are to identify spatial and temporal characteristics of refueling behavior, and to evaluate the variations in refueling behavior across driver population segments. The ultimate goal of this ongoing research effort is to obtain behavioral information that can assist in the design and implementation of initial distribution networks for nonpetroleum transportation fuels. This paper presents initial results toward that goal.

The rest of this paper is organized as follows. The next section briefly describes the survey. Section 3 identifies characteristics of observed refueling behavior relative to the type and location of out-of-home activities. The findings of this section provide

the theoretical and empirical insights that can be applied to existing information sources to develop a predictive model of refueling locations; such a model could be used to evaluate the effectiveness of alternative distribution networks for a new fuel. The following three sections test the generality of the findings from Section 3. Section 4 examines whether the basic characteristics of refueling behavior differ systematically across drivers of different characteristics. The analysis is extended in Section 5 by investigating how the reasons stated by drivers for selecting refueling stations varies across drivers and refueling locations, and how those motivations are correlated with driver attributes and behavior. Section 6 summarizes the study results.

2. DRIVER SURVEY AND SAMPLE CHARACTERISTICS

As reported in our earlier paper (Sperling and Kitamura, 1986), drivers of noncommercial gasoline vehicles were interviewed at retail fuel outlets before and, in the case of self-service customers, during refueling.† Interviews were conducted at seven locations in northern California that were chosen to represent a range of land use patterns and proximities to freeways. Drivers were interviewed at these stations during various time periods of the day, with an even distribution between weekdays and weekends. The following information was collected: characteristics of the trips made immediately before and after refueling; characteristics of the vehicle, driver and driver's household; vehicle utilization patterns; criteria and motivations for selecting the refueling outlet; and driver's sensitivity to fuel price and fuel availability.

The survey was designed with the intent of conducting an exploratory analysis of dominant relationships and patterns in refueling behavior, and not necessarily to generalize refueling behavior across the population of drivers. Even so, although the sample was not drawn randomly from the population of northern California drivers, some indication of the representativeness of the finding is obtained by tabulating across survey locations. Differences across survey locations are reported when relevant in the text. The survey locations are grouped as follows: 1) the small city of Woodland with approximately 30,000 resident nestled in a farm area; 2) suburbs, consisting of two survey locations, one in suburban Concord in the San Francisco Bay Area (population 3,253,000), and one in the sprawling Sacramento metropolitan area (county population 848,000); 3) central business districts (CBDs), consisting of two service stations in downtown Berkeley (population 120,000) in the San Francisco Bay Area, and two in downtown Sacramento; and 4) a service station adjacent to a ramp of a major freeway (I-80) in a low density commercial zone in the city of Emeryville between the Berkeley and San Francisco downtowns [the sample size at each survey location is given in Sperling and Kitamura (1986)].

As a rough test of how closely the sample represents the population of drivers, the distribution of vehicle ages was compared to data for northern California from the California Department of Transportation (Caltrans; Ochoa and Ramsey, 1981). The distributions from the two sources are remarkably similar (see Table 1). The only notable difference is that our sample slightly under-represents vehicles two to three years old (model years 1981–82 for our survey, model years 1977–78 for Ochoa and Ramsey) and over-represents those six to seven years old. These discrepancies, however, may be due to annual fluctuations in vehicle sales. Overall, we conclude there is good agreement between the two surveys (the difference is significant at the 5% level, or at $a = 5\%$, but not at $a = 1\%$). Although the sampling limitations must be borne in mind while interpreting the results of this study, we expect that the current sample offers a reasonably accurate picture of refueling behavior in northern California.

3. CHARACTERISTICS OF REFUELING BEHAVIOR

This section attempts to identify the relationship between the location of refueling and the locations of other activities pursued by a driver. Because refueling is typically performed in connection with other out-of-home activities, the routes of trips made by the driver in pursuit of daily activities will approximately define an area in which refueling will

†The population is defined in this survey as the set of drivers who refueled on a given day. This definition is preferred over alternative, more typical definitions such as the set of all drivers or all households in the study area.

Table 1. Sample validation by vehicle age distribution

	Vehicle age (years)							
	0–1	2–3	4–5	6–7	8–9	10–11	≥12	Total
Refueling survey	10.80	12.50	15.10	17.80	11.20	10.00	22.60	100.00
Cal. DOT survey*	11.10	14.60	15.50	14.60	12.20	10.40	21.60	100.00

*Weighted average of the distribution for the Sacramento (1978) and San Francisco (1980) metropolitan areas (source: Ochoa and Ramsey, 1981, Table 21, p. 66). Weights are developed according to the distribution of observations between the two areas in the refueling survey.

be performed. The linkage between refueling and other out-of-home activities is first examined in this section. The main focus is on whether refueling tends to be performed in connection with some types of activities, or whether it is linked randomly to out-of-home activities. Following this, we examine locational patterns of refueling relative to the driver's daily activities. The distribution of refueling locations relative to home, work, and activity locations is examined in order to describe and characterize refueling locations more precisely. Because of the omnipresence of gasoline outlets, spatial refueling patterns of gasoline-vehicle drivers are relatively constrained. Observed patterns therefore may be interpreted as representing preferences exhibited under conditions most favorable to refuelers. By applying findings on refueling preferences to existing mapped databases of urban land use and spatial trip distributions, likely patronage patterns for any refueling outlet in a network can be determined for any urban area.†

Linkages with other activities

The type of activity pursued immediately before and after refueling (which we refer to as origin and destination activity) are summarized in matrix form in Table 2. Note that 107 (or 7.0%) of 1,521 drivers in the sample made the trip solely to refuel, not en route or on the return from some out-of-home activities. Such unlinked refueling is most frequent at the suburban survey locations in Concord and Sacramento (12.4% of all refuelling trips), and least frequent at the freeway-based Emeryville station (less than 1%). In another similar survey of gasoline-vehicle drivers conducted in Davis, a small university city of population 38,000 in northern California, unlinked refueling trips represented approximately 10% of total trips (Dingemans, *et al.*, 1986).

Analysis of the present survey responses indicated that male drivers and, at the suburban locations, older ($\geq$ 45 years) drivers tend to engage in unlinked refueling. It was also found that unlinked refueling is performed by drivers who frequent a particular station ("more than half the time"). Analysis of the survey results did not indicate any further association between unlinked refueling and the driver's attributes and attitudinal measurements.

Approximately three quarters of the drivers (1,137) refueled on the way to or from home. Home-based refueling is the predominant pattern. After home-based activities, the most frequent activities at the origin end of the refueling trip are shopping and work: the most frequent destination activities are shopping, recreation and social visits. Inspection of the matrix indicates that drivers tend to refuel on the trip from work to home (160 cases) more than from home to work (123 cases)—presumably because of the tight time constraints that are present before work.

The question of whether refueling tends to be performed in connection with certain types of activities was examined by comparing the above linkage matrix with a trip-purpose interchange matrix estimated from the Caltrans origin-destination surveys in northern California (Ochoa and Ramsey, 1981).‡ If the linkage between refueling and other activities lacks any systematic tendencies, then the two matrices must be proportional to each other and constant scaling of one should approximate the other. On the other hand if the linkage does possess some tendencies, then the two matrices will exhibit different patterns. Our analysis indicated that the fraction of work is much larger and that of shopping much smaller in the matrix that involves refueling. Social or recreational activities as destination activities are also over-represented in the matrix of refueling trips.§ These tendencies are consistently observed across the four location groups.

The finding that work is connected to refueling more frequently than expected suggests that refueling is performed at a proportionately greater rate during work trips than during other trips. The result also implies that refueling tends to be performed along the driver's commuting route, with perhaps little or no deviation from it. The strong linkage between commuting and refueling may be a mere

†The fact that observed refueling behavior is conditioned on the supply of existing refueling opportunities must be recognized in interpreting the statistical results presented in this section. The spatial distribution and attributes of refueling outlets do reflect driver's refueling preferences because the location decisions made by the fuel distributors must accurately assess the presence of refueling demand at each candidate site. This leads to interactive and recursive relationship between observed refueling behavior and the distribution of refueling locations; refueling behavior is conditioned by the presence of outlets, while the spatial distribution of outlets is influenced by refueling demand, which is an aggregate of refueling behavior. Potentially this simultaneity would result in biased identification of refueling behavior with its characteristics over-represented in survey statistics. Qualitative conclusions, however, are not likely to be invalidated because of this simultaneity.

‡Several trip-purpose interchange matrices available from Ochoa and Ramsey (1981) were weighted by metropolitan area and day of the week to create a matrix that best matches the sample of our survey. Ideally the matrix obtained from our survey consists of a subset of those trips contained in the trip-purpose interchange matrix; the matrix from our survey includes only those trips where refueling takes place en route from the origin to destination, while the matrix obtained from the Caltrans surveys includes all driver trips, with or without refueling intervening.

§It is probable that our survey sample understates these tendencies. The sample does not contain drivers refueling after 8:00 p.m., presumably under-representing the involvement of social and recreational activities. It is also possible that the linkage with work is more intense than the survey results indicate because it was not always possible to maintain the intended sampling rate of drivers during afternoon peak periods, resulting in an under-representation of commuters refueling after work. These possible biases imply that work, social and recreational activities are even more frequently connected with refueling than found in this study.

Table 2. Activities before and after refueling

Activity at origin	Activity at destination					
	Home	Work	Business	Shopping	Social	Total
Home	107	123	47	190	182	649
	(7.0)	(8.1)	(3.1)	(12.5)	(12.0)	(42.7)
Work	160	40	24	38	13	275
	(10.5)	(2.6)	(1.6)	(2.5)	(.9)	(18.1)
Business	24	13	16	8	5	66
	(1.6)	(.9)	(1.1)	(.5)	(.3)	(4.3)
Shopping	184	14	10	85	32	325
	(12.1)	(.9)	(.7)	(5.6)	(2.1)	(21.4)
Social	120	9	1	28	48	206
	(7.9)	(.6)	(.1)	(1.8)	(3.2)	(13.5)
Total	595	199	98	349	280	1521
	(39.1)	(13.1)	(6.4)	(22.9)	(18.4)	(100.0)

( ) = Percent of grand total.

reflection of the typically long distance of commuting trips. At the same time, repeated exposure to the same refueling opportunities along the commuting route may be the critical factor; because of this intense exposure, the driver's mental map of refueling opportunities will be biased toward opportunities along the commuting route. Commuters and their commuting routes are perhaps an important consideration in designing an effective distribution network for new fuels.

Refueling location relative to home, work, and activity locations

A large fraction of refueling locations lie within a short distance of either the origin or destination locations. Drivers tend to refuel at the beginning or toward the end of the journey. Table 3 indicates that 71.9% of refueling locations are within 5 min of either the trip origin or destination, while approximately 60% of trips took 15 min or longer.† This same tendency holds across all location groups. The corresponding percentages are 78.7 for the small city of Woodland, 78.5 for the suburban group, 75.9 for the CBD group, and 46.1 for the freeway location in Emeryville. The freeway-based outlet shows a distinctively low percentage, but this location attracts long distance commuters and only 28.5% of the drivers interviewed there had trips shorter than 20 min.

Refueling locations tend to be closer to the trip origin than to the destination, as shown by the strong asymmetry of the matrix in Table 3; the over-represented upper triangle indicates that trip time from refueling location to destination is longer than that from origin to refueling location. This is again consistently observed across the four location groups. The ratio of the total trip frequency in the off-diagonal cells of the upper triangle to that of the lower triangle is 2.30 for the small city, 1.69 for suburb, 3.13 for CBD, and 2.12 for the freeway location. This tendency to refuel near the beginning of a trip is an indication of drivers' risk-averse behavior.

Since most trips involving refueling originate or terminate at home or work, it is not surprising that the location of refueling also tends to be near the residence or workplace (Table 4). Among the 1,273 drivers who reported having a work destination (including school), 545 (42.8%) refueled within 5 min of their residence location, and 468 (36.8%) within 5 min of their work location. Since the average home-to-work trip length estimated from our survey is 25.6 min‡ this analysis indicates that commuters' refueling locations are clearly and heavily skewed toward the driver's homes and workplaces.

The proximity of refueling locations to trip ends indicated by the cross-sectional distributions of Tables 3 and 4 implies that each driver over time tends to refuel more frequently at outlets close to home, work, or activity locations. For example, among those drivers who reported that their homes were within 5 min of driving from the refueling locations, 59.9% indicated that they refueled there more than half the time. The corresponding sample-wide value is only 44.8%. Presumably drivers have refueling locations near home or work that they frequent, but occasionally situations arise that lead them to refuel elsewhere.

The finding that drivers tend to refuel at locations

†Trip times between refueling locations and activity sites as reported by drivers are used in the statistical analysis of this study. It is widely recognized that reported trip time, which is to a large extent based on the respondent's guesswork, may not always possess a desired level of accuracy. This problem, however, is not considered as critical in this study since its objective is to capture the most dominant characteristics and tendencies of refueling behavior.

‡Based on the trip times reported by 268 drivers who were making home-based work trips at the time of interview. The average reported trip lengths obtained from statewide surveys are 17.1 and 17.8 min for the Sacramento and San Francisco metropolitan areas, respectively. The statewide average is 24.2 min (Ochoa and Ramsey, 1981, Table 42, p. 318).

Table 3. Refueling location relative to the origin and destination

Trip time from origin	Trip time to destination (min)					
	0–5	6–10	11–20	21–30	>30	Total
0–5	408	127	128	87	120	870
	(27.8)	(8.7)	(8.7)	(5.9)	(8.2)	(59.4)
6–10	71	65	38	15	27	216
	(4.8)	(4.4)	(2.6)	(1.0)	(1.8)	(14.7)
11–20	52	30	55	26	20	183
	(3.5)	(2.0)	(3.8)	(1.8)	(1.4)	(12.5)
21–30	27	7	8	23	12	77
	(1.8)	(.5)	(.5)	(1.6)	(.8)	(5.3)
>30	33	10	19	14	43	119
	(2.3)	(.7)	(1.3)	(1.0)	(2.9)	(8.1)
Total	591	239	248	165	222	1465
	(40.3)	(16.3)	(16.9)	(11.3)	(15.2)	(100.0)

( ) = Percent of grand total. Percentages may not add up to marginal totals due to rounding errors.

in the vicinity of home, work, or activity locations suggests that refueling is in general performed in areas familiar to the driver, i.e. areas that are detailed in drivers' mental maps. It may be inferred that drivers will refuel before making trips to less familiar areas. The finding also supports the hypothesis that the choice of refueling location is conditioned on home, work and out-of-home activity locations, or more precisely, on the routes of trips made to link these locations.

In summary, the location of refueling is largely determined by and linked to the location of home and out-of-home activities, especially work. We also found that the refueling stop is not randomly distributed along the length of a trip, but rather clustered at the beginning or end; in particular, close to home and work locations. Origin-destination surveys conducted in the past in most metropolitan areas of the U.S. offer a rich database to determine the spatial distribution of home, work and other out-of-home activity locations, and therefore provide a basis, in combination with the above findings, to design an initial distribution network for new fuels.

4. CORRELATIONS BETWEEN REFUELING PATTERNS AND DRIVER AND VEHICLE ATTRIBUTES

Conventional travel behavior analysis would seek to determine relationships between characteristics of the individuals and their behavior; in other words to determine if the characteristics of refueling behavior as observed in the previous section vary systematically across drivers. If refueling characteristics vary as a function of the attributes of the driver and vehicle, then it is desirable to identify groups of drivers who share the same characteristics. In the following section relationships between spatial and temporal patterns of refueling and driver and vehicle characteristics are tested.

Statistical association between variables representing the driver and vehicle and those representing spatial and temporal patterns of refueling is determined by analyzing two sets of multiple classification tables. Each table in the first set is formulated using trip time from origin to refueling location (O), trip time from refueling location to destination (D), time of day (T), day of week (D), and a measure of driver

Table 4. Refueling location relative to the residence and work locations

Trip time from work	Trip time from home (min)					
	0–5	6–10	11–20	21–30	>30	Total
0–5	238	53	92	52	33	468
	(18.7)	(4.2)	(7.2)	(4.1)	(2.6)	(36.8)
6–10	95	51	37	11	10	204
	(7.5)	(4.0)	(2.9)	(.9)	(.8)	(16.0)
11–20	103	33	72	25	14	247
	(8.1)	(2.6)	(5.7)	(2.0)	(1.1)	(19.4)
21–30	55	17	24	50	8	154
	(4.3)	(1.3)	(1.9)	(3.9)	(.6)	(12.1)
>30	54	16	28	9	93	200
	(4.2)	(1.3)	(2.2)	(.7)	(7.3)	(15.7)
Total	545	170	253	147	158	1273
	(42.8)	(13.4)	(19.9)	(11.5)	(12.4)	(100.0)

( ) = Percent of grand total.

or vehicle attribute (X). The second group of tables are formulated using the indicators of trip time from home (R) and trip time from workplace (J), rather than from origin and destination, together with T, D, and X as defined above. The time of refueling is represented by four time-of-day categories and two day-of-week categories (weekday vs. weekend). The definitions of the variables and their categories are presented in the Appendix.

Note that different spatial aspects are represented by the two sets of tables. The first set uses variables for trip times between the origin and destination activity sites and the relative position of refueling site between the two. The second set of tables, on the other hand, uses trip time variables to represent the refueling location relative to the home and work locations of the driver. Nonworkers for whom work location cannot be defined are excluded from the second set of tables. Accordingly, factors that have a strong effect in one set of tables do not necessarily have as much effect in the other.

The log-linear model of classification table analysis is used to estimate the association between driver and vehicle attributes and refueling patterns (for discussions of the method, see, e.g. Fienberg, 1977). The significance of such association is examined using models denoted as [ODTW,X] and [JRTW,X]. These models assume that a significant interaction exists among O, D, T, and W, or among J, R, T, and W (these interaction terms are denoted by ODTW and JRTW, respectively). The models at the same time assume that the driver or vehicle attribute, X, does not interact with the other variables which represent spatial and temporal characteristics of refueling. If the model fits the observation, it implies the statistical independence of variable X and we may conclude that the attribute variable is not significantly associated with the refueling pattern. On the other hand, if the model is unable to replicate the observation, it indicates that the vehicle or driver attribute is related to spatial and temporal patterns and that the relationship needs to be incorporated to accurately describe variations in observed behavior.

Results of the log-linear model analysis are summarized in Table 5 for four sets of attribute variables.† The discussion of this section is mainly on the first two sets of variables. The first set of attributes is socioeconomic and demographic in nature. When X is specified as number of cars per household, the model has a significance level of 1.14% for the first formulation (ODTW), but is not significant for the second (JRTW). The result indicates that car ownership is significantly associated with the time (and therefore distance) traveled to and from the refueling site, but not with the spatial distribution of refueling locations relative to home and work locations. The difference is partly due to the exclusion of nonworkers in the second formulation. Further inspection of the results indicated that the variation in trip lengths between weekdays and weekends is the main reason for the failure of the first formulation. We hypothesize that for drivers (or households) with a given number of cars, the location of refueling relative to home and work location does not vary significantly between weekdays and weekends (and therefore the second formulation fits the observation), but the location of activity before or after refueling does (and therefore the first formulation does not fit).

None of the other socioeconomic and demographic variables that are tested here—age, sex, employment, number of adults in household, and household income—show any significant association with the refueling pattern. Apparently socioeconomic and demographic variables are not correlated with spatial and temporal aspects of refueling behavior. This finding is significant, given that income is often used as a predictor of consumer behavior.

Table 5. Association of driver and vehicle attributes with temporal and spatial distribution of refueling locations

Driver or vehicle attribute (X)	Significance level ( ) of log-linear model: [ODTW,X]	[RJTW,X]
1. Socioeconomic and demographic attributes		
No. of cars	.011	.63
Age	.81	.18
No. of adults	.68	.83
Income	.23	.98
Sex	.13	.12
Employment	.48	–
2. Vehicle attributes		
Model year	.031	.071
Car size	.75	.67
Car value	.65	.99
Commute frequency	.26	.56
VMT/year	.43	.0055
Primary vehicle	.74	.76
3. Refueling attributes		
Refueling frequency	.23	.024
Regularity of visit	<.00005	<.00005
4. Attitudinal attributes		
Price sensitivity	.23	.015
Primary reason	.0022	.011
Importance of fuel availability	.33	.62
Ranking of fuel availability	.99	.99
Trendsetter	.70	.93

Note: Categories of the respective variables are: Trip time (O,D,R,J, all in min): ≤5, 6–15, >15; Age (in years): 16–24, 25–34, 35–44, ≥45; No. of Adults: 1, 2, ≥3; Income: <$20,000, $20,000–$29,999, $40,000–$59,999, ≥$60,000; Model Year: ≤75, 76–79, ≥80; Car Size: Subcompact, Compact, Intermediate, Large, Others; VMT/Year: ≤7,000, 7,001–12,000, 12,001–20,000, 20,001–25,000, >25,000; Price Sensitivity: ≤3¢, 4–10¢, >10¢; Primary Reason: Gasoline Price, Accessibility, Other. See Appendix Table for definitions and categorizations of other variables.

†The statistical package used is the PDP-11 version of BMDP Statistical Software.

The result complements an earlier finding that socioeconomic variables are also not correlated to refueling attitudes (Sperling and Kitamura, 1986).

A relationship does exist between refueling patterns and a second group of attribute variables, those related to the vehicle and its usage. Two variables, model year and vehicle-miles traveled (VMT) per year, are shown to be associated with the spatial and temporal patterns of refueling. Further examination indicated that the spatial distribution of refueling locations becomes more dispersed around the home base as VMT increases, but that the location of refueling relative to the trip origin and destination remain unchanged. In other words, the relative position of refueling within a trip does not change with VMT, but the location of the trip relative to the home base does. The differences in refueling patterns in this case are due to differences in the distribution of activity sites and trips around home and work, which is correlated with vehicle mileage. The other vehicle-related attributes—size, value,† number of weekly commuting trips, whether primary vehicle—are not significant.

In summary, it is found that spatial and temporal characteristics of refueling patterns in general do not vary across drivers of different socioeconomic and demographic characteristics or with vehicles with different attributes. Number of vehicles owned and vehicle-miles driven, on the other hand, are significantly correlated with trip length and activity locations, and with refueling patterns. Refueling behavior appears to be determined by factors most directly related to refueling, i.e. vehicle ownership and usage, and not by income and other factors often used in describing individuals.

5. CRITERIA FOR SELECTING REFUELING LOCATIONS

This section attempts further measurement of variation in refueling behavior, but focuses on variation in stated reasons for choosing refueling locations. In the survey, drivers were requested to state from a prepared list‡ the three most important reasons they decided to refuel at the retail outlet where they were being interviewed. The responses are used in this section to determine how the reasons for selecting refueling locations vary across drivers and across survey locations, and to analyze how they are correlated with the attributes of drivers and vehicles, and with other aspects of refueling behavior. For simplicity of presentation, only the first most important reason (hereafter referred to as the "primary reason") is discussed; findings from our analysis of second and third reasons were essentially the same.

†The value of a car is determined as the average 1985 Bluebook price for the model and year of the car.

‡The list of reasons for selecting refueling locations presented to survey respondents during the survey included: price, near shopping, convenient to home, convenient to work/school, near freeway, accepts credit card, has full service, service is fast, friendly, running out of gas, and other.

Primary reasons for selecting refueling locations

Not surprisingly, sample-wide statistics indicate that price of gasoline is a primary concern for a majority of drivers (33.9%), but accessibility to home (20.8%), work (8.0%), and freeways (6.6%) are also important reasons for selecting fuel stations. A relatively small number of respondents cited service attributes such as acceptance of credit cards as the primary reason. Availability of full-service islands is cited only by 0.7% of drivers, even though about 10% of the respondents refueled at full-service pumps.

The distribution of primary reasons for choosing refueling sites varies greatly across the survey locations (Table 6). As expected, proximity to the freeway and immediate needs for gasoline are frequent primary reasons for the drivers refueling at the freeway-based Emeryville station, indicating that decisions to stop at that station had a large component of spontaneity. On the other hand, price is the primary reason for more than half of the refuelers at the suburban locations, and service quality is valued by a fraction of the CBD refuelers that is larger than the statistical expectation. Because of this variation, possible effects of locations are carefully examined in the following analysis by estimating the significance of the interaction terms involving primary reason, attribute variable, and location.

Variations in primary reasons

Only a few socioeconomic and vehicle attribute variables are significantly associated (at $a = 5\%$) with the primary reason. The significant variables are frequency of vehicle use for commuting, car value, and sex (at $a = 2.9\%$, 0.05%, and 4.1%, respectively. None of these variables show significant variations at $a = 10\%$ in their effects across the four location groups). Variables that did not show significant association are model year, car ownership, car size, VMT per year, age, employment, income, and number of adults in the household (excluding trip time variables which showed expected correlations with accessibility as the primary factor). It was found that individuals who use their cars for commuting on a weekly basis, and those who drive more expensive cars, tend to choose refueling locations more because of accessibility than gasoline price. Commuters with expensive cars evidently value time more highly. Although the effect of sex is significant, no interpretable tendency emerged from the analysis.

Two variables, frequency of refueling and price sensitivity (measured as the decrease in gasoline price that will substitute a given additional distance to travel for refueling)§ are significantly associated with the primary reason (with $a = 2.4\%$ and

§In this study, price sensitivity is derived from the response to the question, "If you knew there was a station exactly like this one located two miles out of your way that was selling exactly the same gasoline but at a lower price, would you go there instead 1) if 3¢ cheaper per gallon? 2) if 6¢ cheaper? 3) if 10¢ cheaper?

Table 6. Primary reasons for selecting the fuel outlet where interviewed

	Price	Accessibility		Service attributes	"Running out of gas"	Total	N
		Home/Work	Freeway				
Small city (Woodland)	35.6	40.1	1.9	15.4	7.1	100.0	267
Suburb	53.0	28.5	.6	12.4	5.5	100.0	508
CBD	32.8	30.3	4.4	22.1	10.5	100.0	458
Freeway site (Emeryville)	1.4	24.8	25.2	12.1	36.5	100.0	282
Average	34.2	30.4	6.5	15.8	13.1	100.0	1515

*Includes acceptance of credit cards, full service, quick service, and friendly attendants.

$a < 0.005\%$, respectively). Frequent refuelers tend to choose a refueling site because of accessibility. Drivers with higher price sensitivity tend to choose a refueling site because of price, while accessibility tends to be the primary reason for those with lower price sensitivity. The latter relationship identified by the survey is logically consistent and indicates that drivers are rational actors. Locational effects are again not significant at the 5% level for the two factors.

The patronage of the survey stations by respondents (i.e. the relative frequency of refueling at the survey stations as indicated by respondents) is also strongly correlated with the primary reason ($a < 0.005\%$). The drivers who were refueling at stations that they regularly visit cited price (at the suburban and CBD locations) or accessibility (at the freeway location) as the primary reason with a much higher-than-expected frequency. Price and accessibility appear to be the two major factors contributing to drivers' selection of their preferred "regular" refueling stations.

Overall, the analysis has shown a logical matching between primary reasons stated by drivers and characteristics of refueling sites. A strong trade-off between price and accessibility is also indicated by the analysis. On the other hand, associations between primary reasons and driver and vehicle attributes are found to be weak. This general lack of association may be an indication that reasons for selecting refueling location vary from time to time and that the same driver chooses refueling site for different reasons depending on the situation. It also indicates that drivers are relatively homogeneous in their motivations for selecting refueling location.

6. CONCLUSION

The statistical analysis of this study offers an overall characterization of refueling behavior. Refueling behavior was found to be only weakly correlated with demographic and socioeconomic descriptors of the driver. On the other hand, variables representing car ownership and utilization are strongly associated with refueling behavior. Refueling behavior can be sufficiently described by factors most directly related to refueling—those relating to the car and its usage.

This study has identified a number of patterns in refueling behavior. The findings offer rich information that is valuable in predicting likely refueling locations given the spatial and temporal distribution of trips. In particular the following is important for development of an initial distribution network for a new fuel: drivers tend to refuel in areas that are detailed in their mental maps, e.g. in the vicinity of home and workplace; drivers tend to interrupt their journey near the beginning or end, rather than in the middle, in order to refuel; refueling is frequently performed in commuting trips, while it is linked with shopping with less-than-expected frequency; and single-purpose refueling is not uncommon. When combined with existing databases that offer the distribution of trips in a metropolitan area, these findings will comprise an essential set of relationships for establishing the spatial distribution of refueling locations in the area that will be most acceptable to drivers of nonpetroleum vehicles. As strategic locations for initial outlets, the analysis at this stage points to locations along high-volume commuting routes. As suggested above, however, more detailed and quantitative evaluation of the network of potential sites is possible and should be conducted using the study results.

In closing, we note that this study of refueling behavior uses an inductive approach to generating knowledge. Several hypotheses were formulated to guide the design of a survey questionnaire, but we had little theory or data to use as a basis. The objective of the survey was to generate a data base so as to explore refueling behavior and attitudes. This paper presents insights from that survey. The insights are expressed as empirical relationships. A future challenge for investigators of refueling behavior and, more generally, travel behavior, is to construct generalizable theories that explain behavior not necessarily with economic utility theory, but in sociological and psychological terms.

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APPENDIX.—DEFINITIONS OF CATEGORICAL VARIABLES IN THE ANALYSIS

Variable name [definition]	Categories
No. of cars [No. of cars owned by household]	1) 1, 2) 2, 3) 3 or more
Car per adults [No. of cars divided by no. of adults]	1) $\leq 1/3$, 2) $1/3 < x \leq 1/2$, 3) $1/2 < x < 1$, 4) $1 \leq x$
Age [Age of driver in years]	1) 16–24, 2) 25–34, 3) 35–44, 4) 45–64, 5) 65 and over
No. of adults [No. of persons with age 18 yrs, or older in household]	1) 1, 2) 2, 3) 3, 4) 4 or more
Income [Total gross annual household income]	1) –$14,999, 2) $15,000–$19,999 3) $20,000–$29,999, 4) $30,000–$39,999, 5) $40,000–$49,999, 6) $50,000–$59,999, 7) $60,000 and over
Sex	1) Male, 2) Female
Model year [Model year of the vehicle being refueled during the survey]	1) –72, 2) 73–74, 3) 75–76, 4) 77–78, 5) 79–80, 6) 81–82, 7) 83–
Car size [Defined according to vehicle type or weight of the model]	1) Subcompact, 2) Compact, 3) Intermediate, 4) Large, 5) Sports car, 6) Pick-up truck, van
Car price [Average present value of the model by year]	1) –$5,500, 2) $5,501–$10,299 3) $10,300 and over
Commuting frequency [No. of days per week the vehicle is used by the respondent to commute to work or school]	1) None, 2) Up to 3 days, 3) 4 days or more
Primary vehicle [A vehicle is a primary vehicle for a driver if he or she does not usually have access to another vehicle]	1) Yes, 2) No
VMT/year [Vehicle-miles traveled per year by the vehicle]	1) –7,000, 2) 7,001–10,000, 3) 10,001–12,000, 4) 12,001–15,000, 5) 15,001–20,000, 6) 20,001–25,000 7) 25,001–
Long distance trips [No. of tours of 200 miles or longer taken in the past year]	1) 0, 2) 1, 3) 2–3, 4) 4–5, 5) 6–10, 6) 11–20, 7) 21–
Refueling frequency [Frequency of refueling per week]	1) Once or less, 2) 2 or 3 times, 3) 4 times or more
Regularity of visit [Respondent's regularity of visiting the survey station]	1) 50% of time or more, 2) 25–50%, 3) Less than 25% of time
Self/full service [Type of service driver used]	1) Self service, 2) Full service
Price sensitivity [Gasoline price difference per gallon that would induce the driver to drive extra 2 miles to another otherwise identical service station]	1) 3¢ or less, 2) 4–6¢, 3) 7–10¢ 4) More than 10¢
Primary reason [The most important reason for the driver in selecting the sruvey station]	1) Gasoline price, 2) Convenient from stores, 3) Convenient from home, 4) Convenient from work, 5) Close to freeway, 6) Accepts credit cards, 7) Offers full service, 8) Fast service, 9) Friendly, 10) Running out of gas, 11) Other

Variable name [definition]	Categories
Importance of fuel availability [Driver's concern with diesel fuel availability should he/she be considering to buy a diesel vehicle]	1) Very concerned, 2) Somewhat concerned, 3) Not concerned
Ranking of fuel availability [Ranking of diesel fuel availability as a reason for not having purchased a diesel vehicle]	1) First, 2) Second, 3) Third or lower, 4) Not ranked
Trendsetter [Driver's preference to purchasing new products as they come on market]	1) Always, 2) Sometimes, 3) No
Time of day	1) 6:00–9:59 a.m., 2) 10:00 a.m.–12:59 p.m., 3) 1:00–3:59 p.m., 4) 4:00–7:59 p.m.
Day of week	1) Weekday, 2) Weekend