Projecting Use of Electric Vehicles from Household Vehicle Trials: Trial and Error?

UCI-ITS-WP-98-2

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January 1998

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Presented at the 77th Annual Meeting of the Transportation Research Board, Washington, D.C., January 1998.

1. Objectives and Scope

Electric vehicles (EVs), in the form of cars and light-duty trucks (sport utility vehicles, pickup trucks and vans), are currently being test marketed by most of the major auto manufacturers. EVs might become widely available in the future marketplace because of a combination of clean-fuel legislation, environmental concern on the part of buyers, and potential operating cost advantages. Discussions of the advantages and disadvantages of EVs can be found in Greene (1994), Kreith, et al. (1995), Sperling (1995, 1997), and Gould and Golob (1997). Since only a few prototype vehicles are on the road, researchers currently use a number of indirect methods involving survey data to assess consumer acceptance of these vehicles.

Personal trials, where vehicles are placed within households and driven over normal conditions for an extended period of time, would appear to hold great potential in assessing consumer preferences. The value of extended field research, like trials has been proposed by Turrentine, et al.1992) since it well recognized that consumers probably lack a frame-of-reference or context to evaluate a new product, like the electric vehicle. Household trials seem to overcome this difficulty, and provide direct evidence of how households might adapt to a vehicle with limited range, and overnight recharging. However, there has been little published research about vehicle trials, in part because they are infrequent, and in part because the results are usually proprietary. In the few cases where academics have been involved in sensitive market research trials, they have shown that methodological issues can be disseminated within the research community without compromising issues of managerial confidentiality (Urban et al, 1996).

In 1995-96, the authors participated in an eight-month long trial of prototype EVs, with the proviso that we could use some of the results for academic research. We were particularly interested in comparing data collected from trials with matched data collected from a panel survey. Our objective was to better understand vehicle trials as a source of information for transportation planning and market research, beyond the usual consumer preference information gathered for vehicle design purposes. The methodological issues were of particular concern, for as we discuss in the next section, trials provide useful data at one level, but they can also introduce new sources of bias and uncertainty to data collection and interpretation. We also investigated how perceptions towards EVs would change with the "hands-on" experience of a trial.

In this paper we report findings from this trial, with a particular emphasis upon the methodological issues. We intentionally do not discuss purchase intentions, and focus, instead, upon a broader set of results. An objective is to provide transportation planners with useful data about characteristics like vehicle miles travelled, intra-household vehicle switching, and long trip taking when there are multiple data sources from the same respondents, including travel diaries and pre- and post trial panel survey data. This provides insight into how households might choose to use future electric vehicles, and it also addresses the issue of whether trials are an effective and efficient data collection method. The research is expected to provide useful information for those who wish to organize and interpret data from future consumer vehicle trials and it also provides more limited evidence about how households would use future electric vehicles that had a limited range.

2. Previous Research, and Limitations of Trials Research

Various methods have been used to study electric vehicle demand, but almost all of them are based on some use of survey research. Complex and advanced survey designs are used, to compensate for the fact that most respondents do not have direct knowledge of the technology. Following a brief review of these survey methods, we consider whether trials provide a useful and alternative means of data collection.

Models for forecasting EV demand have been developed based on stated preference (SP) surveys, in which respondents choose among hypothetical future vehicles concocted according to an experimental design (Beggs, *et al.*, 1980, Hensher, 1982, Calfee, 1985, Golob, *et al.*, 1993, Bunch *et al.*, 1993, Segal, 1995). The most complicated of these SP demand models also use revealed choice data on vehicle holdings (Train, 1980, Brownstone, *et al.*, 1996,) and vehicle holdings combined with transaction histories (Bunch, *et al.*, 1996). Advanced survey techniques involving multi-stage in-depth interviews, gaming simulations, and activity analysis have also been used to investigate how households could use battery EVs with limited range between home recharging (Kurani, *et al.*, 1994; 1996). Unlike traditional surveys, these studies try to record the process through which preferences develop towards a new technology.

Vehicle demonstrations, sometimes called "product clinics," are also used to assess consumer demand. They provide an opportunity to "kick the tires" of vehicle mock-ups, or test drive prototype vehicles, at a central location in a controlled environment. Surveys conducted before and after the clinics can be used to assess the effects on consumer acceptance of exposure to vehicles (e.g., Turrentine, *et al.*, 1992). Another method has been use of experimental simulations, where respondents "walk through" their process of choosing a vehicle (Urban, *et al.*, 1990, 1996). Somewhat related to this are focus groups, but they seldom present consumers with hands-on technology (Chéron and Zins, 1997).

A common criticism of the methods used to forecast EV demand, such as the stated preference survey, the multi-stage-in-depth interview, and focus groups, is that they elicit information about a product, for which people do not have direct information or knowledge. Thus, respondents are giving a top-of-the mind answer, which does not reflect how they would actually respond, under real conditions. The limitations of interviews and surveys are well understood and discussed by transportation researchers (Ampt *et al.*, 1985). Further criticisms of survey research are that the links between what people say in surveys and what they actually do are tenuous; also, respondents may answer a survey in less than truthful ways; for example, to influence the outcome of a study, or because they don't remember a particular fact.

Trials seem to side-step many problems of survey research, since some data, such as vehicle miles of travel (VMT), stops and starts, and recharging activity, can be logged electronically with recorders. Many trials use survey research as a complement, since valuable data is collected if respondents fill out travel diaries showing the purpose of their trips, and complete questionnaires with 'before' and 'after' measures. Presumably, survey research conducted during a trial is more realistic than other types of survey research about the EV, because people have the opportunity to experience the technology directly. There have been little data available to test this postulate.

While direct experience with the product affords new insight, trials introduce their own set of methodological concerns. The likelihood of a 'Hawthorne' effect increases, where positive affect (in this case, for the EV) is spurious. The Hawthorne effect was discovered some years ago among researchers who were staging a trial of lighting conditions in a Western Electric factory in Hawthorne, California. The researchers were surprised to find that production levels improved across all experimental manipulations. It was determined that the impetus for change was psychological; namely, singling out factory workers for the trial, and providing them with 'management' attention, improved productivity (see Adair 1980, Greenwood *et al,* 1983). Staging an EV trial could alter behaviour since participants are singled out and receive special attention. In the trial that we describe, several of the respondents were spotlighted by the local media, and a few trial participants were videotaped for archive materials.

A related measurement problem concerns the length or duration of the trial. Although a trial may change activities or habits, it is generally believed that over time usage will revert to more regular patterns as the novelty factor declines. When drivers purchase a new car, their VMT may change over the short run, as they get accustomed to the vehicle and perhaps give demonstration rides. Similar issues are likely to occur in EV trials, and may confound reliable measurement of VMT. The unresolved issue however, is the time period of the adjustment.

A third complexity of trials is the limited length of time over which users can experience the product (vehicle) across a range of conditions. In a vehicle trial, drivers are not required to service and maintain the vehicle, and they are unlikely to change a tire, or take the vehicle on holiday. Their experience of the technology is truncated, vis-à-vis everyday use. Another difficulty is that participants in a trial seldom have the opportunity to experience competing (vehicle) technologies. As a result, some trials may provide reactions to a specific category or product, rather than opinions about a new product class.

3. Research Design

3.1. Sample Selection and Characteristics

In the present vehicle trial, efforts were taken to minimize the problems cited above. The duration of household trials was two weeks, so that respondents had some time to familiarize themselves with the vehicles and use it routinely. We also incorporated some questions in a travel diary to test for use of the vehicle in 'demonstration' trips. To help control for a "Hawthorne Effect," participants were mostly chosen from a sample of respondents for which we had pre-trial-selection opinion data. Although we were not able to randomize drivers across EV makes and models, we did administer our survey instrument in two other trials that used different types of EVs. Unfortunately, results from these other trials are proprietary.

The vehicle trials were conducted in Southern California in 1995 and 1996. They were organized by a domestic automobile manufacturer in co-operation with two regional electric utilities. The sample was drawn from households who had previously participated in a state-wide University of California study about vehicle transactions and usage. The five criteria used to select participants are listed below. Importantly, the criteria did not include VMT since we wished to explore how drivers coped with restricted vehicle range.

Trial selection criteria were:

1. live within 40 mile of a designated electric vehicle service center,
2. be a customer of the major electric utilities in the area,
3. agree to participate and complete all forms, surveys, and interviews,
4. have a verifiable good driving record,
5. home has a 240 volt, 30 amp circuit, or is easily retrofitted for it.

Based on the first of the screening criteria there were not enough qualified households in the draw. Therefore, a small second sample of sixteen households was selected from a different University of California panel on clean fuels. The characteristics of the combined sample (N = 69) are given in Table 1.

3.2. Protocol and Data Collection

The vehicles used in the trials were manufacturer's prototypes. Between each trial they were sent to a designated electric vehicle service center for cleaning and testing. The two-passenger vehicles were equipped with an advanced climate control system, sound system, and in-car phone. The exterior of the vehicle was not especially marked, and the body style did not differ radically from current vehicles. Participants were told that the EV range between recharges would depend on driving conditions and topography, but that it could do at least 100 miles under optimal conditions.

Table 1: Respondent Characteristics in Vehicle Trials

Characteristic	Breakdown	
Gender		
Male	60%	
Female	40%	
Education		
high school	10.3%	
some college	29.0%	
college	29.8%	
post-college	31.0%	
% of HH with children	32%	
% of HH with 1	26%	
	Mean	Std. dev.
Age	45.54	10.97
VMT- first vehicle *	13,704	6,226
VMT- second vehicle*	12,784	11,163

*annual vehicle miles of travel per vehicle, estimated by respondent

Trial data were collected using several methods. First, pre- and post-trial survey instruments were designed that incorporated many questions used in the panel survey. These survey instruments were first tested in 1994 by an electric utility, during an eighteen month long trial of six conversion EVs.

A travel diary with extensive testing from other transportation studies was administered. Respondents recorded the departure and arrival times, the distance, and the purpose of all individual trips. We were not able to control for the fact that diary-keeping may have sensitized respondents to their daily VMT and induced them to make some travel modifications, when the limited range vehicle arrived. The diaries were vehicle based and completed for conventional-fuel cars over a seven day period before the trial, so that we could compare new travel patterns when the EV entered the household. When the EV entered the household, respondents were specifically asked to garage (not use) the gasoline vehicle which they had filled out the seven day diary for, and a rather symbolic exercise was taken of 'putting away the keys' and replacing them with the new set for the EV. We would have preferred to have had a seven day vehicle diary filled out for all household vehicles, but the organizers of the trial thought that this was impractical. The driver of the EV was reminded to use the EV, just as they did their conventional gasoline car. In post-test interviews we asked about intra-vehicle switching, and we do not believe that respondents did this for work, or work related trips. However, there might have been some tendency for households with children to use a different vehicle for social and recreational trips, because the electric vehicle was a two-seater model. The period of time in which participants filled out the diaries varied due to logistical problems, such as delivery of EVs, hook-up of all utility meters, and holiday schedules. The actual EV diary periods varied from nine to eighteen days, and, for analyses of travel activity we only use 63 of the 69 trials in which participants kept diaries for at least four (but usually seven) days on use of their conventional vehicle prior to arrival of the EV, and then kept diaries on use of the EV as a replacement for that same conventional vehicle. The distribution of diary time periods for these participants is shown in Table 2. The full data set has 1,849 conventional-fuel vehicle trips and 3,904 EV trips with reliable distance information.

Table 2: Number of Trial Participants by Diary Time Periods

Number	Number of conventional fuel vehicle days									row
of EV days	4	5	6	7	8	9	10	11	12	totals
9		2								2
10	1	2	1	1						5
11			2	3						5
12			2	5	1	1		1		10
13	1		2	15	2					20
14	1	1	3	6						11
15	1	1	1	2	1		1			7
16				1						1
17									1	1
18				1						1
column totals	4	6	11	34	4	1	1	1	1	63

4. Estimates of VMT

In keeping with the methodological intent of our research we were interested in people's knowledge of daily VMT. We begin by looking at respondents' estimate of VMT, for both conventional-fuel vehicles and EVs. There were three sources of observation: travel diary records, pre-trial surveys, and post-trial surveys.

The travel diaries data consist of trips made over a total of 1256 days, and 98.5% of these days (1237) had reliable distance information for all recorded trips. Our analyses were based on these 1237 days. As shown in Table 3, the mean daily VMT for conventional-fuel vehicles (43.9 miles) is 3.8 miles greater than the mean daily distance for EVs (40.1 miles). However, this difference in means is not statistically significant at the 95% confidence level ($p = .092$, one-tailed test).

Table 3: Daily Vehicle Miles Travelled for Conventional-fuel and Electric Vehicles (in miles) (N=63)

Statistic	Conventional-fuel vehicle	Electric vehicle
mean (μ)	43.9	40.1
Standard deviation (σ)	17.8	14.0
Standard error of the mean	2.2	1.8
Median	40.2	39.1
Number of diary days	424	813

Results from the pre-trial and during-trial opinion surveys corroborate these results. Participants were asked two questions: "If your household owned an electric vehicle, how many total miles per week do you think your household would drive it for trips to work or school?" and "If your household owned an electric vehicle, how many total miles do you think your household would drive it for all other trips (trips other than work or school)?" These questions were included in a survey that was conducted before each vehicle trial, and were repeated in a survey that was conducted on or just before the last day of the vehicle trials. A daily VMT of between 38 and 40 miles can be inferred from both of these weekly estimates (Table 4). The large standard deviations for both the diary and opinion data are not surprising, given the known distributions of daily VMT across vehicles in multi-vehicle households (Greene, 1985).

Table 4: Estimated Use (in miles) of the Electric Vehicle for Work Trips and For Other Travel

	Work travel per week		All other travel per week		Total estimated VMT	
	Mean	Std. dev.	Mean	Std. Dev.	Per week	Per day
Pre-trial	172.6	122.4	91.0	67.4	263.7	37.7
Post-trial	175.6	108.0	104.5	77.4	280.1	40.0

From the survey results tabulated in Table 4, we conclude that participants' estimates of EV usage for work trips did not increase as a result of the trial. Estimated use of the EV for all other travel increased modestly, but this change is not statistically significant at the $p = .05$ level ($t = 1.61$). The larger standard deviation associated with VMT for conventional-fuel vehicles (Table 3) suggests that conventional vehicles were driven over longer distances than the EV, as expected. Participants did a reasonably good job of estimating how much they would drive an EV, even though they did not drive it as far as the conventional-fuel vehicle that the EV replaced.

Both before and after the trial, participants were also asked how much range an EV *should* provide, under two separate recharging scenarios: (1) a restrictive one where charging could occur only overnight and (2) a more liberal one, with partial charging occurring during the day. Even in the latter condition, there was still an overall expectation that range should be more than 100 miles (Table 5). Under the restriction of overnight recharging only, the mean desired range was 121 miles before the trial and 126 miles after the trial. For the scenario that included daytime recharging possibilities, the means before and after were 110 miles and 111 miles, respectively. Neither of these pre-trial versus post-trial differences were statistically significant (overnight charge: $t = 0.89$; daytime charge, $t = 0.14$). Desired ranges are consistently greater than 100 miles, but travel diaries indicate that the average VMT was under 40 miles per day.

Table 5: Desired Daily Range for an Electric Vehicle

	Overnight Recharge only		Daytime Recharge avail.	
	Mean (μ)	SD (σ)	mean (μ)	SD (σ)
Pre-trial	120.6	59.6	110.4	64.3
Post-Trial (during trial)	126.1	58.0	111.3	66.0

The discrepancy between desired range and mean daily VMT has been observed in research by Chéron and Zins (1997), Kurani, *et al.* (1996), Nesbitt (1992), and others. Across multiple research methods, from focus groups to consumer choice modeling, there is a common finding that regardless of how frequently people actually travel long distances, they desire a vehicle versatile enough to make longer trips. There may be a deep-seated expectation that cars should be able to accommodate relatively rare long distance trips and unplanned extra trips that might be required after a normal day of vehicle use, or a psychological association between vehicle ownership and freedom to travel with wider boundaries.

4.1 Novelty of the Trial and VMT Estimates

Just as acquiring a new car might lead to higher VMT in the short term, it is likely that EV drivers would take special trips to test the vehicle and demonstrate it to others. The novelty of an EV would likely accentuate such a new-vehicle syndrome. Recognising this potential, the travel diary incorporated a category of trip making called "for demonstration purposes." This was broadly defined, and could include travel that the respondent initiated by themselves, or with passengers. There were 411 such demonstration trips occurring over a period of 233 days, with a mean trip distance of 4.2 miles. If days with demonstration trips are eliminated, the mean daily VMT for EVs decreases from 40.1 to 38.9 miles (Table 6). This revised difference between the means for conventional-fuel vehicles and EVs is statistically significant at the 95% confidence level (p=.035, one-tailed test). The EV was driven for normal trips even less than it initially appears, and the gap between its usage and conventional-fuel vehicles is greater. We conclude that, for everyday trip making excluding infrequent long trips, a two-passenger EV with 100 miles range requiring overnight recharging at home would be used 88% as much the conventional-fuel vehicle it would replace.

The question next arises as to whether the difference in mean VMT are due to differences in the number of trips, mean trip lengths, or both. Mean daily trip rates for both vehicle types are shown in Table 7. Mean trip lengths were also calculated. They were 10.2 miles for conventional-fuel vehicles, 9.3 miles for EVs on days without demonstration rides, and 8.6 for EVs on all days. Demonstration trips raise EV trip rates and lower mean trip lengths. Excluding days with demonstration rides, most, but not all, of the difference between conventional-fuel and EV use is due to lower mean trip rates for the EVs. This is probably due to increased rates of trip chaining, as well as substitution of destinations. A plot of aggregate mean trip length versus trip rate for each of the trial participants, for each of the two vehicle types, is shown in Figure 1. In this plot we can find no systematic differences between the vehicles.

Table 6: Daily VMT for Conventional-fuel and Electric Vehicles (in Miles) Including and Excluding Days with "Demonstration Ride" Trips (N=63 trials)

Statistic	Conventional-fuel vehicle	Electric Vehicle: Days with Demonstration Rides Excluded	Electric Vehicle: All Days Included
Mean	43.9	38.9	40.1
Standard deviation	17.8	15.2	14.0
Standard error of the mean	2.2	1.9	1.8
Median	40.2	38.8	39.1
Number of days	424	580	813

Table 7: Daily Trip Rates for Conventional-fuel and Electric Vehicles (in Miles) Including and Excluding Days with "Demonstration Ride" Trips (N=63 trials)

Statistic	Conventional-fuel vehicle	Electric Vehicle: Days with Demonstration Rides Excluded	Electric Vehicle: All Days Included
Mean daily trip rate	4.30	4.17	4.67
Standard deviation of trip rate	1.69	1.57	1.73
Standard error of the mean	0.21	0.20	0.22
Median	4.14	3.83	4.23
Number of days	424	580	813

Did the novelty of using the EVs change trip destinations, and the daily use of the vehicle? We examined the purpose of individual trips, and then measured daily VMT with and without days in which "demonstration rides" took place. In Table 8 we compute the daily VMT, given that a particular trip was taken (a day can include multiple trips for different purposes). For each of these trip purposes, there are no significant differences between trip taking with or without the demonstration rides. However, it can be observed that the conventional-fuel vehicle is used for longer trips, such as work-related and social or recreational ones. Since the EV seated only two people, this is likely to have limited some trip-making with the vehicle.

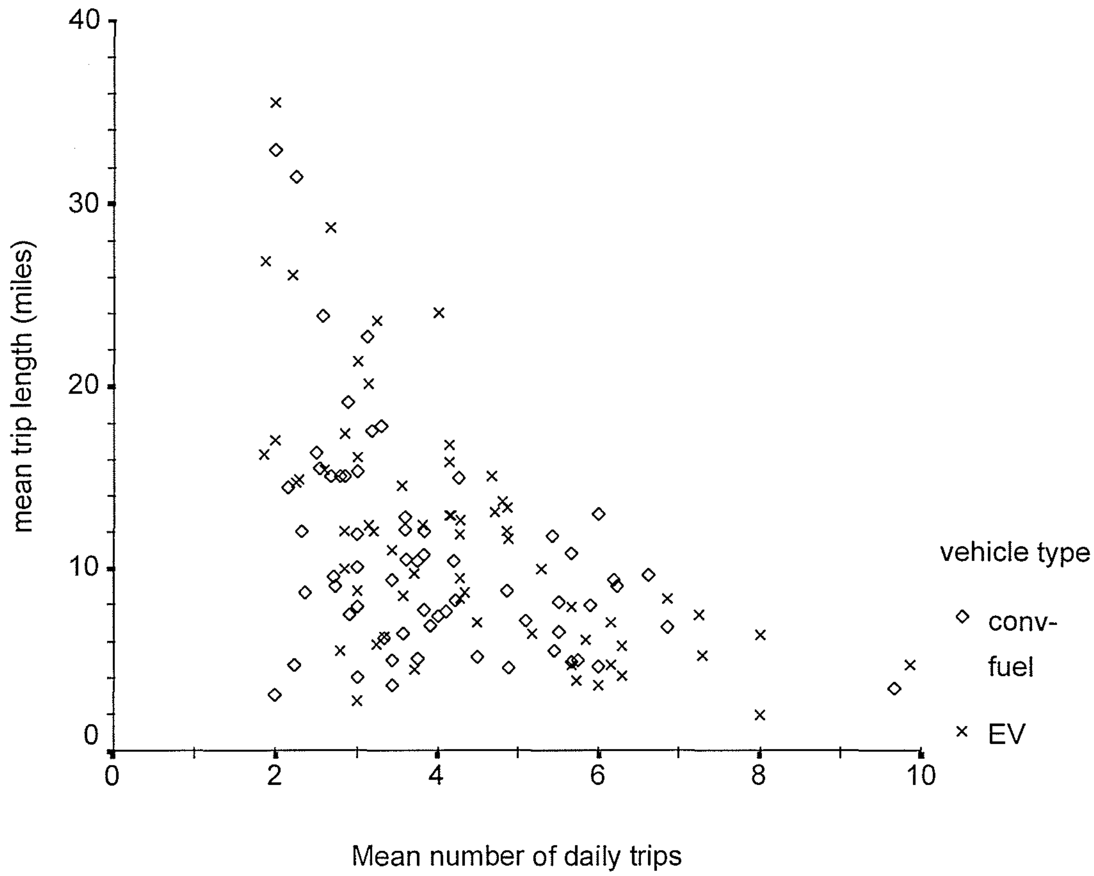

Figure 1: Mean Daily Trip Length versus Mean daily Trip Rate by Vehicle for Each trial

The results for demonstration rides point to a related methodological issue, about the suitable (time) duration for vehicle trials. On the one hand, VMT at the beginning of any trial might be greater than what could be expected under routine conditions as drivers experiment with the new vehicle. They may use the vehicle more in order to gain experience with it and to provide demonstration rides for others. On the other hand, the use of a new EV presents entirely new issues, like acquiring familiarity with the range of the vehicle, learning how the vehicle performs under different levels of discharge, and assessing the reliability of the gauges. As respondents gained experience, their daily VMT might increase. There is no published evidence about this, but because our trial diaries covered from nine to eighteen days, with most being about two weeks, we could observe temporal effects.

Table 8: Daily VMT for Conventional-fuel and Electric Vehicles by Trip Purposes (in Miles)

Days with trips involving:	Conventional-fuel Vehicle.			Electric Vehicle Demonstration Rides Included			Electric Vehicle Days with Demonstration Rides Excluded		
	μ	σ	N	μ	σ	N	μ	σ	N
Journey to work	44.7	28.8	249	45.1	24.4	450	42.5	23.4	331
Work-related	62.2	43.1	74	54.2	26.4	129	53.2	26.5	79
Errands, child care, school	41.5	25.7	124	42.9	23.8	269	40.9	23.0	179
Shopping	39.6	33.1	99	39.0	24.9	215	36.8	25.1	162
Demonstration rides				45.0	26.7	233			
Social or recreational	50.9	34.8	147	47.8	26.7	277	44.7	27.4	172
Serve passenger	53.7	38.8	46	45.7	22.0	92	44.7	20.9	61
Return home and other	43.8	32.3	391	41.0	24.8	726	38.3	24.1	529
All days with trips	43.9	35.4	424	40.1	26.0	813	38.9	25.5	580

To test for such effects, we computed a standardized daily VMT for each trial participant, equal to the difference of daily VMT from the mean over all days for their trial, divided by the standard deviation of VMT over all days of their trial. A plot of standardized VMT by diary sequence day is shown in Figure 2. This includes all days, including those on which demonstration rides were recorded. Since the number of EV diary days varied from nine to eighteen, we weighted the observations in a regression of standardized VMT on sequence day. The weights (which sum to the original sample size) were inversely proportional to the number of diary days, so that each participant was accounted for equally. The regression demonstrates a slight increase in VMT over time (Figure 2). However, this increase in VMT is statistically insignificant, the standardized coefficient (β) of sequence day being 0.0138 with a t-statistic of 1.33 ($p = 0.18$).

This result could have been due to a non-random distribution of demonstration rides over the course of the trials, so we re-computed standardized VMT eliminating all days with demonstration rides. The t-statistic for the coefficient of sequence day was 1.09 ($p = 0.28$), confirming that there was no significant increase or decrease in VMT over the course of the trials.

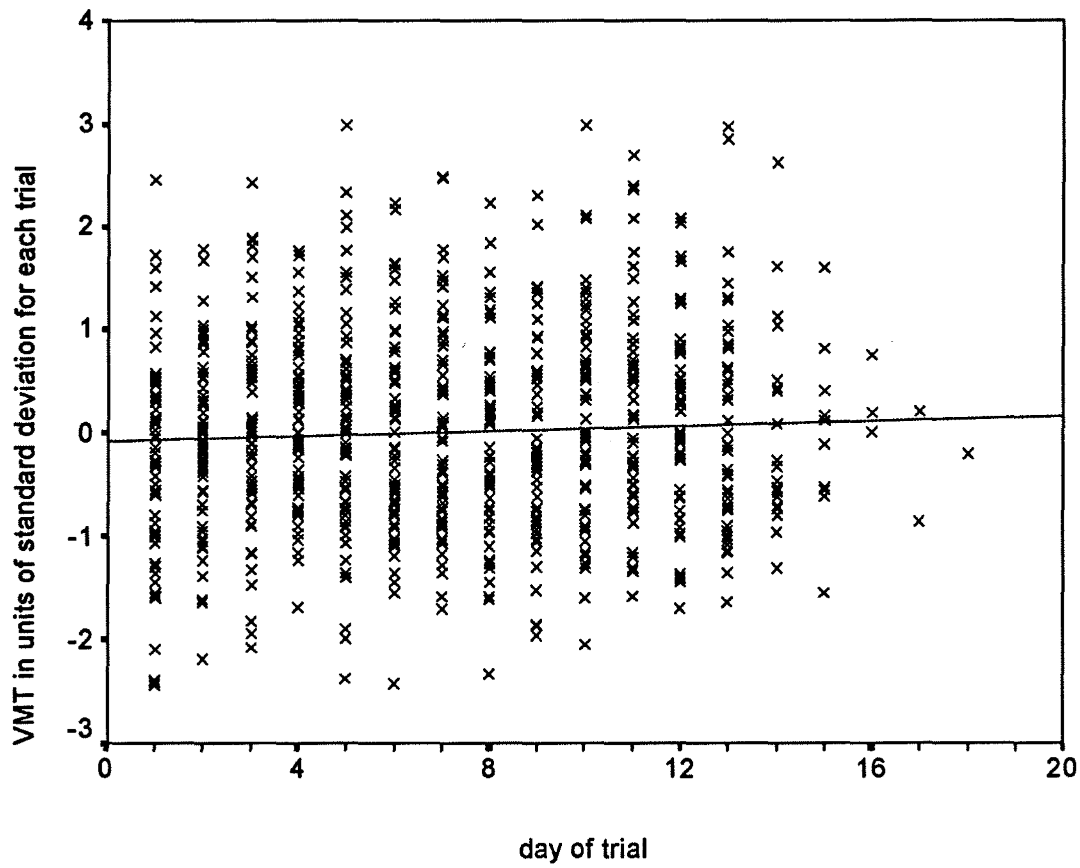

Figure 2: Standardised EV and Conventional-fuel Vehicle VMT
for Each Trial by Sequence Day of Trial, with Regression Function

We can conclude that demonstration rides have no significant effect on the stability of usage over a two-week trial period. Consequently. it might be possible to have a shorter trial period without adversely affecting the quality of the usage data.

5. Estimating EV Use over Longer Periods

5.1 Extrapolation to Long Distance Trip Taking

If a household with more than one vehicle were to replace one of their vehicles with a battery EV, we have estimated from the trials that 88% of the normal everyday trips made with the conventional-fuel vehicle that was replaced would be made with the EV. In order to estimate how much of total annual VMT is likely to be accommodated by the EV, we next need to investigate trip-making behaviour for relatively rare long-distance trips that exceed the range of the EV. Some of these trips might be switched to the remaining conventional-fuel vehicles in the household, some trips might be made by recharging the EV at locations away from home, and some trips might be cancelled, destinations might be substituted, or the trips might be made by other means.

The trials were only two weeks in length and were not conducted during holiday and normal vacation periods, so we could not explore use of the vehicles for longer trips and out-of-town excursions. However, in the panel study that preceded the trials, respondents were asked which of their household vehicles they would 'convert' into an "alternative fuel vehicle that has a more limited range between refueling." In the second part of the panel survey, 40% of the sample, chosen randomly, was asked about how this 'converted' vehicle might be used if were a battery EV with a range given by one of three experimental values, chosen randomly. The ranges tested were 60, 100, and 120 miles.

Respondents were asked to recall the length and number of trips they took on the 'converted' vehicle during the past year that exceeding the experimental value that they were given. The question asked specifically about non-work travel, and many questions that preceded it in the interviews set the context that this particular travel was for holiday or recreational purposes. It was implied that this was a one way trip, since the respondents stopped when they reached their holiday or vacation destination. The wording of some of the actual questions are given in the Appendix, with results reported in Table 9. The last column estimates the annual mileage that would occur on trips that exceed EVs with ranges of 60, 100, and 120 mile, respectively, assuming that the last trip reported was an average trip. For example, if EVs had a 100 mile range, the average household would make eight trips per year, with an average distance of 515 miles, that exceeded this level. This nets 4,170 "excess" miles which cannot be met by a vehicle with a 100 mile range unless the EV is recharged away from home.

Table 9: Annual number and average length of Trips Exceeding Three Experimental Range Values from the 1994 Panel Survey

Experimental Range value (x)	Number of observations	Average trips per year > x miles	Average distance of last such trip	Estimated annual mileage for trips > x miles
60	267	14.25	310.9	4,430
100	254	8.10	515.3	4,170
120	220	6.21	533.2	3,310

The portion of annual VMT represented by these long trips can be calculated by using the panel respondents estimates of annual VMT. Because EVs are a new phenomenon, we focused on usage of relatively new vehicles. The average annual VMT for converted vehicles less than two years old was 14,185 miles (VMT will be lower for older vehicles). Thus, the portion of annual VMT on 'converted' vehicles that is less than 60, 100 and 120 miles is 9,755, 10,015 and 10,875 miles, respectively.

To probe how people might adapt to using an EV, we asked a second set of questions about trip-taking alternatives in both the panel and the trials. Panel respondents indicated what they would do if the trip distance exceeded the experimental range of their 'converted' vehicle (arbitrarily assigned to be either 60 miles, 100, or 120 miles as an experimental design). Ten possible options were suggested for completing the trip. The same options, with the exception of en-route recharging which was clearly not a viable choice for current drivers, were presented in the panel study. Since the same questions were asked, we compare, in Table10, how both groups say that they would cope with longer trips.

Table 10: Stated Decision Making for Long Trips in the Electric Vehicle
(% of respondents choosing option)

Stated option for dealing with trips formerly made on conventional-fuel vehicle, but which exceed the Hypothetical range of the EV that replaced the conventional-fuel vehicle	Panel Survey Experimental Range			Trial 150 mile range	
	60 miles	100 miles	120 miles	Pre-trial	Post-trial
1. Cancel the trip	3	4	3	2	0
2. Make a shorter trip	2	5	5	4	6
3. Make the same trip in one of your hh other vehicles	42	39	36	69	79
4. Borrow a friend's vehicle	4	4	2	0	0
5. Ride with someone else	3	5	4	0	0
6. Rent a car	5	8	9	4	2
7. Take a train, bus, shuttle, taxi, other	3	3	4	2	0
8. Recharge the EV at a service station (en route)	24	27	26	18	10
9.Recharge the EV while parked at or near destination	6	8	8	(NA)	(NA)
10. Recharge at a friend or relative's house	8	5	6	(NA)	(NA)

The most striking result is that in the panel, about 40% consider switching to a different household vehicle. In the trial, this percentage increases to about 80%, but opportunities for away-from home recharging were limited in the trial survey. The two missing options, recharging the EV while parked at or near destination, and recharging the EV at a friend or relative's house, were chosen by approximately 14% of the panel survey respondents. Even accounting for this, trial participants, who had personal experience driving a limited range vehicle, expected to use another household vehicle to complete the trip more often than did the panel survey respondents. Assuming that the proportions choosing the missing recharging options would be the same in the trial survey as they were in the panel survey, we conclude that between 30% and 45% of long-distance trips might be made using an EV with recharging away from home or substitution of destinations to shorten the trip. Between 40% and 65% of these trips would be shifted to other household vehicles.

Based on these analyses, we constructed a scenario of annual use of a battery EV with 100 miles range by combining information from the trials on everyday trip making with evidence on long distance trips from the panel data: On the average, approximately 10,000 miles are driven annually on vehicles on "average" days with trips less than 100 miles. These are vehicles of recent vintage in multi-vehicle households that survey respondents choose as the vehicle they would choose to have limited range. We estimate from the trials that 8,800 of these miles (88%) would be accommodated with the EV; the remaining 1,200 (12%) would potentially be switched to other household vehicles.

If, at the low end, 30% of the estimated 4,000 miles of long-distance conventional-fuel vehicle VMT can also be accommodated with a 100 mile range electric vehicle, while 65% is shifted to conventional-fuel vehicles, the estimated annual EV VMT is 10,000 miles, or 70% of a comparable conventional-fuel vehicle. VMT on the other household vehicle(s) would go up by 3,800 miles. At the high end, we estimate that 45% of long-distance trips can be accommodated with the EV, while 40% would be shifted to the other vehicle(s). Estimated EV VMT is 10,600 miles, or 75% of a comparable conventional-fuel vehicle. Conventional-fuel vehicle VMT would rise by 2,800 miles.

5.2 Intra-household Vehicle Switching

Here we continue to explore evidence about trade-offs between the use of conventional-fuel and EVs. The trial diaries are a valuable source of information because there are seven days of activity data on the conventional-fuel vehicle, which was then replaced by the EV. We compare the assignment of trip taking between electric and conventional-fuel vehicles for 'local' travel activity.

The scatter-plot in Figure 3 shows for two-vehicle households (n=42) the daily mean VMT of conventional-fuel and electric vehicles. For low values of VMT, EV

VMT was often equal to or greater than conventional-fuel vehicle VMT, but the reverse is true for high values of VMT, where perceived EV range presumably came into play. We fit various functional forms for the relationship between mean EV VMT (denoted by VMT_{EV}) and mean conventional-fuel vehicle daily VMT (denoted by VMT_{CFV}), and the best fit was for the power function, $VMT_{EV} = \alpha\, VMT_{CVF}^{\beta}$, which also has the theoretical advantage of passing through the origin. The adjusted R^2 for the regression with a sample size of 63 is 0.468. The constant α is 1.26 (t = 4.00) and the exponent β is 0.630 (t = 7.46).

The power function has a crossover point that predicts that the EV will be used more than the conventional-fuel vehicle it replaced for daily VMT up to approximately 28 miles but the EV will be used less than the conventional-fuel vehicle for VMT beyond that point. This is consistent with switching short trips from other household vehicles to the EV for environmental or potential operating cost reasons, while switching longer tours to conventional-fuel vehicles because of perceived and actual EV range limitations.

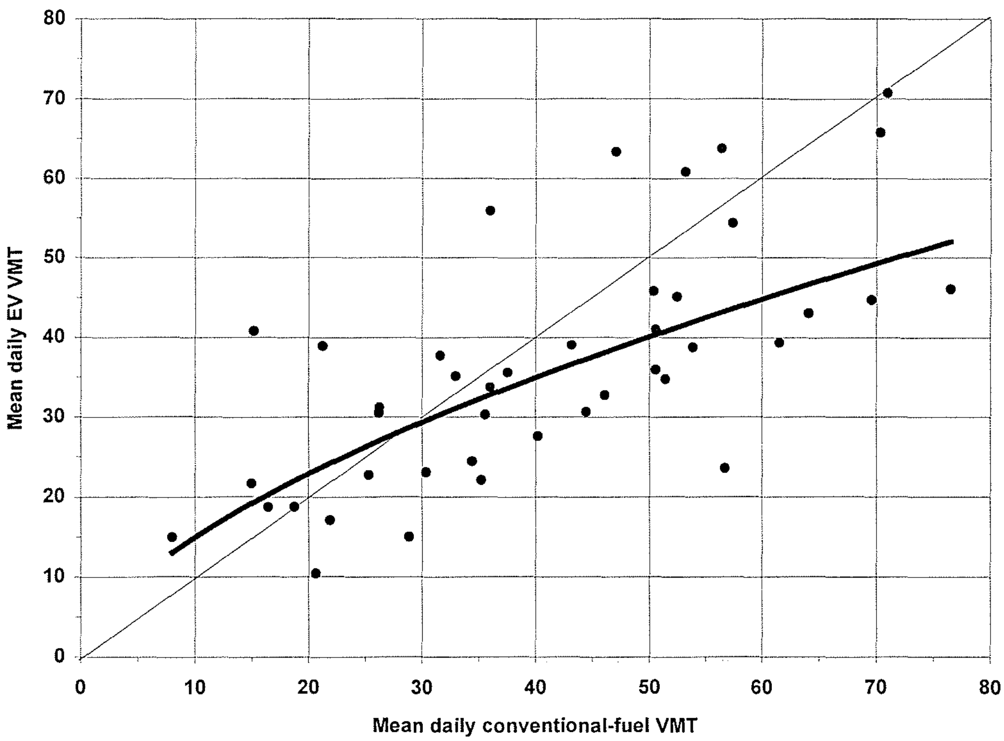

Figure 3: Plot of Observed Mean Daily EV VMT versus Mean Conventional-fuel Vehicle VMT, with Power Regression Function

These data provide further evidence that the electric vehicle is not perceived by multi-car households as a pure substitute for a conventional conventional-fuel vehicle. Introduction of a battery EV into a household fleet will require adaptation in terms of vehicle switching among trip purposes and drivers, such as that described by Nesbitt, *et al.* (1992) and Kurani, *et al.* (1994; 1996). The result is that an EV will be driven substantially less than the conventional-fuel vehicle it replaces, and most of this difference in usage will be shifted to other vehicles in the household's fleet. This shift is consistent with the results produced by recent forecasting models using SP data (Golob *et al.*, 1997).

7. Conclusions and Recommendations

If EVs reach the penetration levels mandated by legislation in California and elsewhere, there will be a diminishing need for trials research. Until then, and as the implementation dates for various mandates approach, trials are likely to increase, since engineers will be anxious to test their product on the road, and marketing people will seek original input. We have argued throughout this paper that although trials are useful for collecting data, the results are not unbiased. We have tried to identify some of the biases that trials introduce, and reconcile differences through a comparison of data collection techniques.

The novelty of participating in an EV trial does lead to exaggerated reports of use. The inclusion of demonstration trips inflated the estimates of daily VMT. A list of travel activities that included demonstration rides helps to identified this bias, and this survey item should be employed in future studies. However, data from the trial travel diaries corroborated external survey results regarding use of EVs for long trips, as conventional-fuel vehicles were observed to be used more on days with longer trips.

All research studies, including trials, are faced with the dilemma of gathering enough information, while not overburdening respondents with data collection. In this study, the sponsors chose to administer the pre-trial, seven day travel diary for only one household vehicle. This limited our ability to study complex intra-vehicle switching, and we had to make inferences about this based on more indirect data techniques. We believe that this is an issue which future trials research may wish to address, and would recommend that multi-vehicle household diaries be used.

One of the more provocative results from this study is that experience with EVs does not change perceptions of desired range. Although the experience of driving an electric vehicle and keeping a travel diary gave users direct feedback that they were usually travelling less than fifty miles per day, there remained an expectation that vehicles should have a standing range of 100 miles or more. This suggests that there might be a VMT threshold which must be overcome for consumers, as concluded by Chéron and Zins (1997). Future research might explore the predicates of this range threshold and how much it varies among segments. For instance, drivers who had a fixed route and easy access to charging ports at destinations away from home might exhibit a lower range threshold.

In this study, respondents were studied over a two week-trial, and there was evidence that this duration was a reasonable period for participation adaptation. Our evidence indicates that it might also be possible to have a shorter trial period without adversely affecting the quality of the usage data. The study also provided evidence that people were fairly accurate at recording daily VMT over this period.

Since VMT and other important measures can be collected using less obtrusive research methods, researchers may have to weigh the costs and benefits of staging vehicle trials. However, for certain types of information, a trial may be essential, particularly for describing detailed behaviors and patterns of vehicle use. For example, when asked about long distance trip taking, people who did not have direct experience with electric vehicles imagined a wide range of options for overcoming its limited range. With the experience of a vehicle trial, drivers did not see the same options to be viable. As other researchers have suggested (Urban *et al* 1996, Kurani *et al*, 1995), respondents must be able to envision how they would use a new technology like an EV.

In this study we used multiple methods and compared results from travel diaries, panel data, and pre- and post-trial surveys. Each source provides a separate perspective of potential EV use. Reconciling the differences among them is a complex but necessary process, since there are as yet, few EVs on the road. Trials held among commercial and fleet users are not likely to yield the same depth of information, nor identify those factors that will facilitate or inhibit consumer demand.

Acknowledgements

The authors are grateful to the Southern California Edison Company (SCE) and the California Energy Commission for partial support of this research. The vehicle trial was facilitated by Ernie Morales of SCE, and was ably co-ordinated by Ken Swertnik. We would also like to thank the vehicle manufacturer, who shall remain anonymous, the L.A. Department of Water and Power, Debbie Brodt and Seyoung Kim. All opinions expressed here are the those of the authors alone, who are also solely responsible for any errors.

References

Adair, J. (1980) The Hawthorne effect: A reconsideration of the methodological artifact. *Journal of Applied Psychology,* **67**: 334-345.

Ampt E.S., Richardson, A.J. and Brog. W., eds., (1985) *New Survey Methods In Transport.* VNU Science Press. Utrecht.

Beggs, S., Cardell, S. and Hausman, J.R. (1980) Assessing the potential for electric cars. *J. of Econometrics*, **16**: 1-19.

Brownstone, D., D.S. Bunch, T.F. Golob and W. Ren (1996) A transactions choice model for forecasting demand for alternative-fuel vehicles. Research in Transportation Economics, **4**: 87-129.

Bunch, D.S., Bradley, M., Golob, T.F., Kitamura, R. and Occhiuzzo, G.P. (1993) Demand for clean-fuel personal vehicles in California: A discrete-choice stated preference study. *Transportation Research*, **27A**: 237-253.

Bunch, D.S., D. Brownstone and T.F. Golob (1996) A dynamic forecasting system for vehicle markets with clean-fuel vehicles. In D.A. Hensher and J. King, eds., *World Transport Research,* **4**: 189-203.

Calfee, J.E. (1985) Estimating the demand for electric automobiles using fully disaggregated probabilistic choice analysis. *Transportation Research,* **19B:** 287-302.

Chéron, E. and Zins, M. (1997) Electric vehicle purchasing intentions: The concern over battery charge duration. *Transportation Research,* **31A**: 235-243.

Golob, T.F., D.S. Bunch and D. Brownstone (1997) Forecasting future vehicle usage using a jointly-estimated revealed- and stated-preference model. *Journal of Transport Economics and Policy*, **31**: 69-92.

Golob, T.F., S. Kim and W. Ren (1996) How households use different types of vehicles: A structural driver allocation and usage model. *Transportation Research,* **30A**: 103-118.

Golob, T.F., Kitamura, R., Bradley, M. and Bunch, D.S. (1993) Predicting the market penetration of electric and clean-fuel vehicles. *Science of the Total Environment*, **134**: 371-381.

Greene, D.L.(1985) Estimating daily vehicle usage distributions and the implications for limited-range vehicles. *Transportation Research*, **19B**: 347-358.

Greene, D.L. (1994) Transportation and energy. *Transportation Quarterly*, **48**: 91-101.

Greeenwood, R., Bolton, A. and Greenwood, R. (1983) Hawthorne A Half Century Later: Relay Assembly Participants Remember, **9**, Issue 2, 217-231.

Gould, j. and T.F. Golob (1997) Clean air forever? A longitudinal analysis of opinions about air pollution and the electric vehicle. *Transportation Research*, Part D, in press.

Hensher, D.A. (1982) Functional measurements, individual preferences and discrete choice modeling: Theory and application. *Journal of Econometric Psychology,* **2**: 323-335.

Kreith, F., Norton, P. and Potestio, D.S. (1995) Electric vehicles: Promise and Reality. *Transportation Quarterly*, **49**: 5-21.

Kurani, K.S., Turrentine, T. and Sperling, D. (1996) Demand for electric vehicles in hybrid households: An exploratory analysis. *Transport Policy*, **1**: 244-256.

Kurani, K.S., Turrentine, T. and Sperling, D. (1996) Testing electric vehicle demand in 'hybrid households' using a reflexive survey. *Transportation Research*, **1D**: 131-150.

Sperling, D. (1995) *Future Drive: Electric vehicles and Sustainable Transportation.* Island Press, Washington, DC.

Sperling, D. (1997) Rethinking the car of the future. *Issues in Science and Technology,* **13**: 29-34.

Sperling, D. and Kitamura, R. (1986) Refueling and new fuels: An exploratory analysis. *Transportation Research*, **20A**: 15-23.

Turrentine T. , Sperling, D. and Kurani, K. (1992) Market Potential of Electric and Natural Gas Vehicles. Institute of Transportation Studies University of California Davis. UCD- ITS-RR-92-8.

Urban, G.L., Hauser, J.R., Qualis, W.J., Weinberg, B.D., Bohlmann, J.D., Chicos, R.A. (1997) Information acceleration: Validation and lessons from the field. *Journal of Marketing Research*, **34**: 143-153.

Urban, G.L., Hauser, J.R. and Roberts, J.H. (1990) Prelaunch forecasting of new automobiles. *Management Science*, **36**: 401-421.

Urban, G.L. Weinberg, B. and Hauser, J. (1996) Premarket forecasting of really-new products. *Journal of Marketing*, **60**:47-60.

Appendix

Sample questions asked in The 1994 Wave of the California Household Vehicle Transactions Panel Survey computer-aided telephone interview (CATI)

1. "Think back to the most recent time your gasoline <year> <make> <model> was driven more than <x> miles, ... About how many total miles was the vehicle driven on this trip?"

(<x> denotes a value of refueling range chosen randomly from three values: 60 miles, 100 miles, and 120 miles).

2. "Imagine that you were to convert one of your household vehicles to an alternative-fuel version that had a more limited range between refuelings. An alternative fuel vehicle would include an electric or natural gas vehicle... Which of your household vehicles would you be most likely to convert?"

3. "Within the past 12 months, how many trips over <x> miles did you actually take in your gasoline <year> <make> <model>?"

(Here <year>, <make> and <model> are those of the *converted limited range vehicle,* and <x> denotes a value of refueling range chosen randomly from three values: 60 miles, 100 miles, and 120 miles.)