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Survey of the Importance of Interregional Availability for Alternative Fuels

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Abstract

Through a preliminary map based survey, the value of local, regional, and interregional alternative fuel stations is estimated in terms of the initial purchase price of an alternative fuel vehicle such as a fuel cell or fast-charge battery electric. Survey respondents placed refuelling locations in order of importance on a map, and evaluated the reduction in value of an alternative fuel vehicle versus a conventional gasoline vehicle given different station conditions. The only stated difference in the vehicles was the number of refuelling locations available. If refuelling were only available at one location near the respondent's home, the vehicle retained 20%-50% of its value for multi-vehicle households, and 0% of its value for most one-vehicle households. For ten optimally located stations, the alternative fuel vehicle retained 55%-100% of its value for multi-vehicle households, and 0% to 100% of its value for one-vehicle households. The station locations chosen by the respondents indicate that even infrequently visited weekend destinations have importance when determining the initial purchase value of an alternative fuel vehicle. Nearby metropolitan areas carried the greatest importance. The most important station was near the respondents home, the median distance for the second most important station was 84km (52mi) and the median value for the third station was 93km (58mi).

Keywords: electricity, hydrogen, infrastructure, EV (electric vehicle), fuel cell

1 Introduction

The value of a hydrogen or fast charge electric refuelling network is poorly understood. While most agree that limited refuelling availability decreases the utility and value of a vehicle, the amount of that value decrease has not been well defined. Specifically, the value of stations outside a customer's own region may have a large effect on the value of a vehicle regardless of the number of times a station outside the region is actually used. A customer may simply want the assurance that a station is available if he or she desires to travel outside the region. Through an online survey with an accompanying map, the value of interregional refuelling availability is assessed.

There are at least three different scales at which refuelling availability can be evaluated: local, regional and interregional. The local and regional scales comprise the availability of refuelling in one's home town and home region. The interregional scale consists of fuel availability outside one's home region. This may include stations that enable trips to weekend destinations, recreational opportunities or extended family.

2 Background

Previous survey based studies [1,2,3]have investigated the effect of fuel availability on alternative vehicle purchase price.. All of these studies quantify the availability of fuel as a percentage of stations offering the alternative fuel relative to gasoline. For example, an alternative-fueled vehicle might be worth $2,000 less than a comparable gasoline vehicle if only 20% of stations offered the alternative fuel.

A study by Bunch et al.[3] estimates that the price for a dedicated alternative fuel vehicle with 10% fuel availability is approximately $8,000 less ($11,110 in 2008 dollars[4]) than a gasoline vehicle with full fuel availability. Conversely, the study found that consumers would pay full price for an alternative fuel vehicle with the same attributes as a gasoline vehicle and an equivalent number of stations. There is a diminishing return in the willingness to pay as the percentage of stations increases. The study indicated that consumers are willing to pay 40% of the $8,000 for the first 20% of stations, and 60% for the last 80% of stations.

A report by Greene [2] suggests that the first 20% of stations to offer an alternative fuel are significantly more important to consumers than in the study by Bunch. This determination was made by examining the effect of reducing the alternative fuel price, not on a reduction in the purchase price of the vehicle. A reduction in purchase price of $1000 to $2000 ($1307 to $2614 in 2008 dollars[4]) is estimated for a vehicle with a limited refuelling network with under 20% of stations, due to limited data, a more accurate estimate could not be made..

Another survey by Segal[1] estimates that the value of a full CNG network versus solely home CNG refuelling is $3050. This is equivalent to $4949 in 2008 dollars[4]. This estimate is very interesting since it simulates the range a vehicle would have with local but no interregional refuelling. However, since home refuelling is an extra convenience, the penalty for having to actually go to a local station may be more than $3050.

2.1 Background Discussion

Two common themes emerge from existing surveys. First, there is no distinction made between the availability of local and interregional stations. Second, the value of fuel availability is expressed in terms of a percentage of gasoline stations offering an alternative fuel. A “percentage of stations” metric implies to the respondent that the fuel is uniformly available over the entire area he or she may desire to travel to in a vehicle. This does little to inform the situation where there is a local or regional rollout of an alternative fuel, but it is not available outside this area. Only the survey by Segal estimates the value of having only a local station insofar as home refuelling can be considered local refuelling availability. However, Segal’s study assumes limited range in conjunction with limited refuelling availability. Consumers may be willing to pay more than Segal estimated for a vehicle with home refuelling and range similar to a gasoline vehicle.

Using a percentage of stations to gauge the availability of an alternative fuel is a convenient way to model availability, but it does not reflect how many stations are needed for a survey respondent to feel comfortable with a certain level of refuelling network. Using a percentage reflects one of two situations. The first situation it represents to the respondent is the probability that his or her favorite local station location is available. For example, if there are 10 local stations and 20% offer an alternative fuel, in the mind of the respondent, 2 out of those 10 are randomly selected to offer alternative fuel. His or her favorite stations may not be among those with the alternative fuel and so this situation is reflected in the aversion to an alternative fuel. In reality, if the alternative fuel station were in the location of his or her favorite station, the percentages are meaningless. That one station could represent 1% or 20% and the respondent may not really care how many other stations had the fuel as long as there was availability a convenient local station.

The other situation that phrasing availability in terms of a percentage may represent to a respondent is the chance he or she will be able to find a fuelling station during an unplanned fuel stop. No one wants to run out of fuel and the more stations there are, the less chance there is of running out of fuel. For example, in a 10% alternative fuel network, the survey respondent may have a mental image of searching for fuel, and only finding the fuel at the tenth station. The aversion to this situation will be reflected in the responses to the value of refuelling availability. Realistically, in a 10% network, an alternative fuel

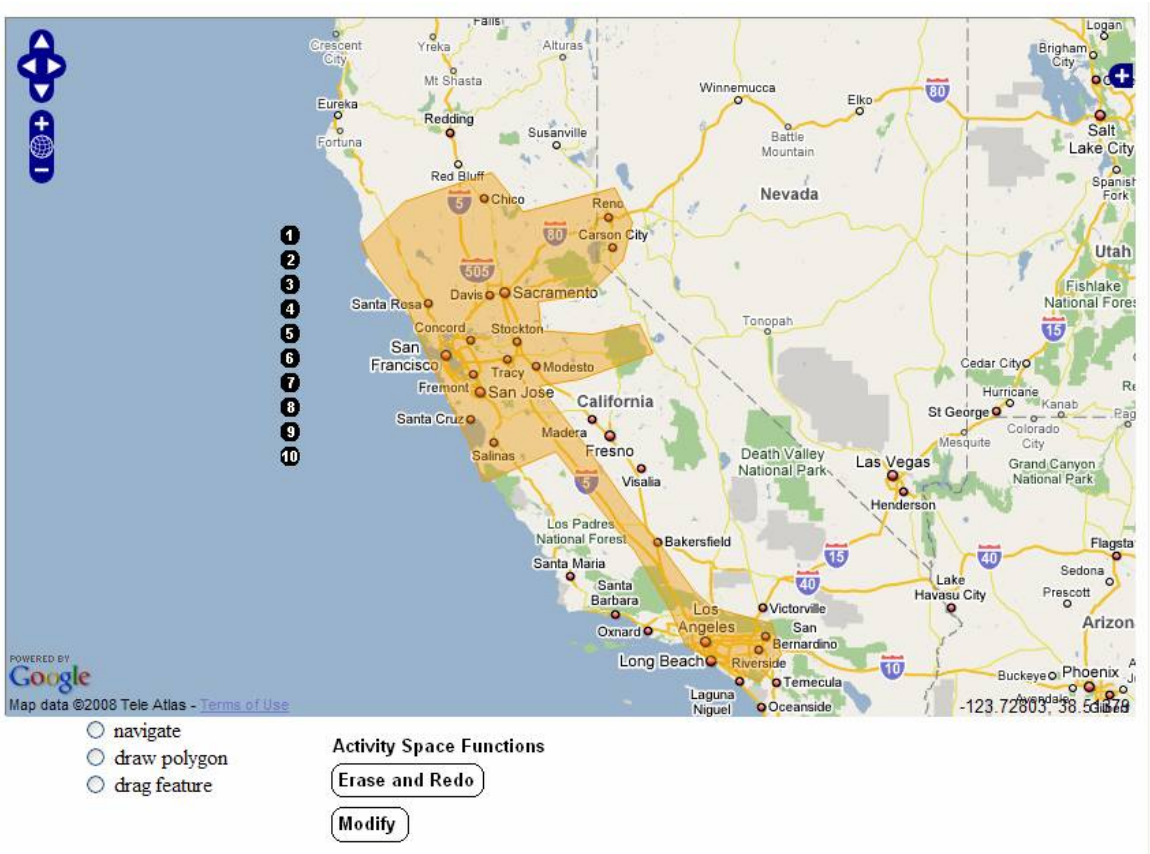

Figure 1: Activity space designation. Stations listed 1-10 shown on the left in the Figure are placed on the map by the respondent.

vehicle owner will not use most of that 10%. Only some of the 10% will be useful to a particular respondent based on his or her travel patterns. In a situation where a consumer had perfect knowledge of where the stations were, either by placing the stations themselves, or having a GPS to inform the consumer where the stations are, fewer stations are likely needed than in the paradigm of randomly encountering a station.

3 Survey Design

This survey attempts to decouple the number of stations needed from a percentage framework in order to answer the question of the extent and importance of refuelling locations for individual consumers. The main application of this approach is to assess the refuelling needs for focused introductions of alternative fuel vehicles in certain cities or regions. In this survey, the only refuelling location that is decided a priori is the "home" station. Assuming these outlets are available, the location of additional stations and their importance in terms of an increase in vehicle purchase price is determined.

There are many factors that are incorporated into the price of a vehicle, but ultimately the choice to purchase is either a "yes" or "no" decision at a certain price. The same is true for alternative fuel vehicles such as fuel cells or electric vehicles. However, there is at least one important difference from a conventional vehicle – the availability of fuel. This factor is not incorporated into the price of a conventional vehicle, except for diesel which has fewer outlets than gasoline. However, during the introduction of a dedicated alternative fuel vehicle such as a hydrogen vehicle or an electric vehicle with fast charging or battery swap capability, the lack of availability of refuelling locations will have an effect on the value of the vehicle.

To explore the value of refuelling away from home, an online survey was conducted. A convenience sample of 20 University of California at Davis employees was used in order to test survey design, and give indications of early results. Results from a full scale survey are not yet

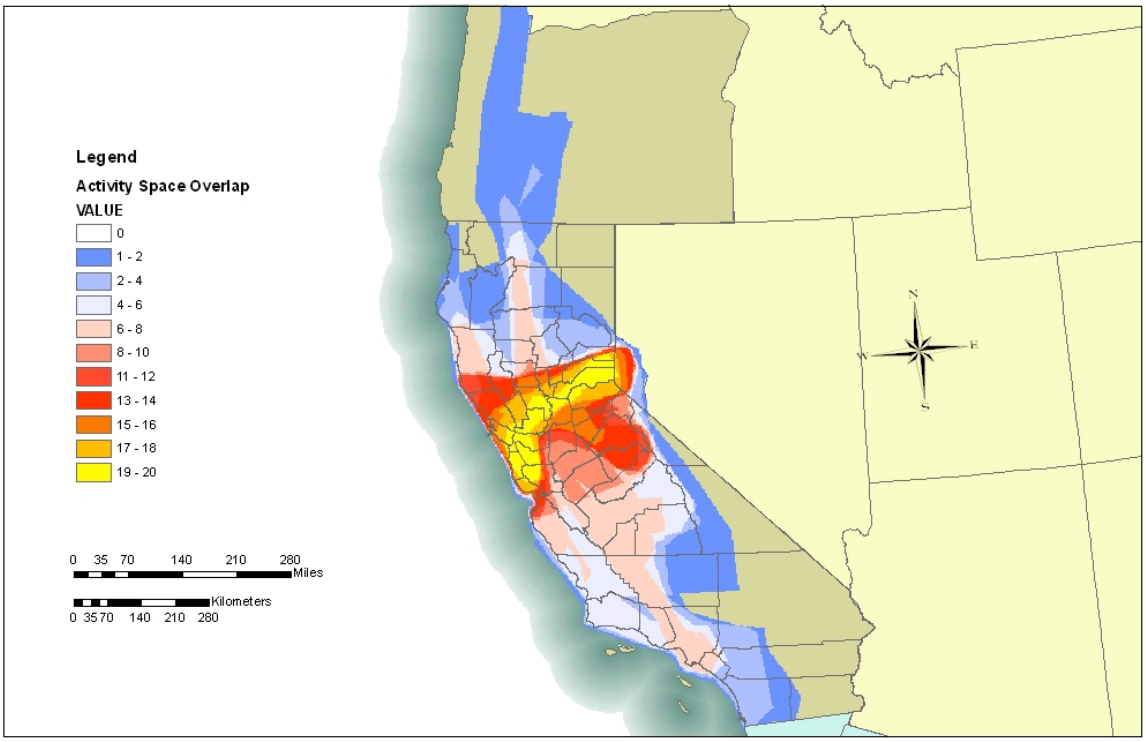

Figure 2: Activity Space Overlap

available due to factors described later. Nevertheless, an attempt was made to have a diverse sample. Twelve lived in the city of Davis, eight lived outside the city. There were eight women, twelve men. Nine were one vehicle households, eleven were multi-vehicle households. The ages ranged from 20 to 62 years old with a median of 28 years old.

Respondents were first asked to define their "activity space" or the region they considered familiar territory[5,6]. An overlay of an example activity space is shown in Figure 1. Although Figure 1 shows a computer map, respondents were given a paper map instead due to difficulties with drawing the activity space on a computer. Next, respondents were asked to place 10 stations to enable travel throughout their activity space. Based on these station placements, respondents were asked a series of questions on vehicle value based on how many of their station locations were available.

Respondents were asked to state the price and vehicle type of their most likely next purchase. A typical answer may be something like a used compact station wagon with an expected price of $10,000. Next, the respondent is asked to compare two vehicles: the gasoline vehicle chosen by the respondent, and an identical vehicle using an alternative fuel vehicle with a varying number of stations. The alternative fuel was not specified, but was described as one that was comparable to gasoline, and was derived from oil just as gasoline. The decision to not specify electricity or hydrogen was to isolate the value of the refuelling network independent of the advanced technology used. For example, many people would pay more for an environmentally friendly vehicle, but this value is highly variable, and only loosely related to refuelling availability. By comparing identical vehicles whose only difference was refuelling availability, the value of that availability can be estimated.

Respondents were first asked to answer: "How much would a vehicle be worth if there were only one station next to your home compared to a gasoline vehicle?" Next, the respondent chooses the next two most important stations (for a total of three) and reassesses the value of the vehicle compared to the conventional vehicle. This process is repeated for six and ten stations.

The unique feature of this survey method is that the respondents choose the value of stations independent of a classification into local, regional, or interregional. In this way we can see the

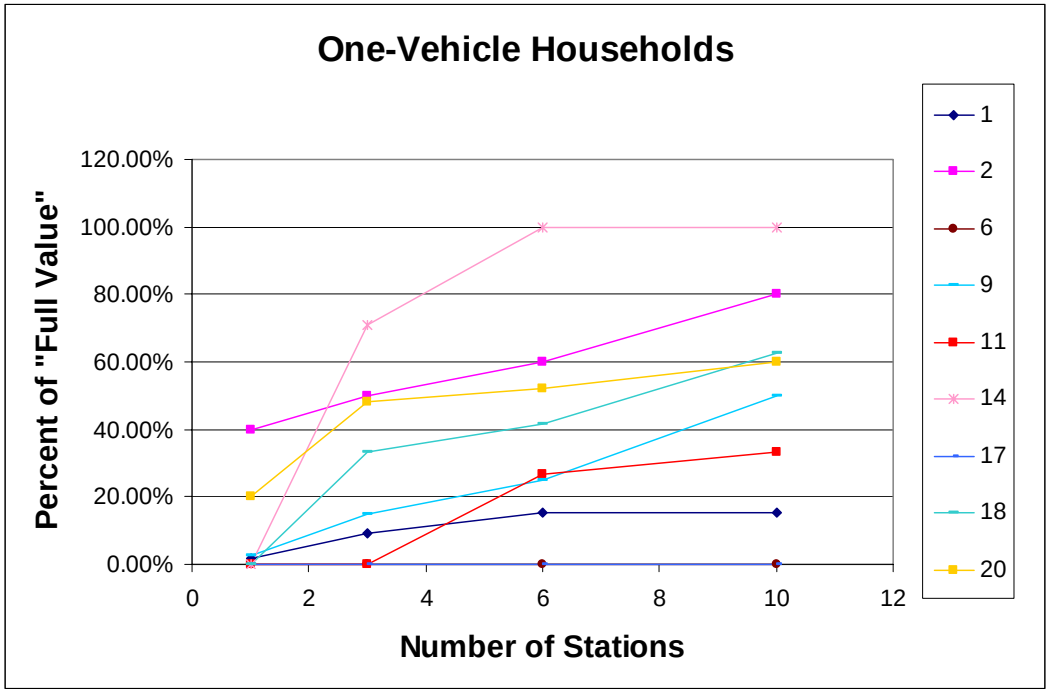

Figure 3: Percent of full vehicle value for one-vehicle households as a function of the number of user defined stations. The networks evaluated were 1, 3, 6, and 10 station networks defined by the user. Each line represents a respondent

progression of value for the each respondent and answer the question of how important are local, regional, and interregional stations? What effect might it have on purchase price?

4 Survey Results

4.1 Activity Spaces

The activity spaces drawn by the respondents reveal which driving areas are important during the life of the vehicle. The overlap in activity spaces can be seen in Figure 2. The overlap of activity spaces in Figure 2 show both variability and commonality in the regions that are important to access. All 20 respondents found the corridor from San Jose in the Bay area to Lake Tahoe important (indicated in yellow). The majority also indicated that Yosemite was an area that they could envision driving to. This map also hints at the psychology of vehicle purchase in the context of fuel availability. Some areas included in the important driving area are not a frequently accessed area, but may still be important in the "Yes" or "No" decision to buy a vehicle at a certain price. Eleven out of twenty indicated that Tahoe was among their top six most important stations and four put it among their top three stations. At most, some respondents stated that they accessed Tahoe once a month, but the majority said they accessed it once every few years. Although not conclusive, the results suggest that infrequently used stations may still be important for consumers' perception of initial vehicle value

4.2 Vehicle Value

The survey results for vehicle value can be broken into two broad groups: multi-vehicle households and single vehicle households. In general multi-vehicle households found greater value in a vehicle with a limited refuelling network. The change in vehicle value as a percentage of the conventional vehicle value is shown for the two groups in Figure 3 and Figure 4. Another way to present the decrease in vehicle value is in terms of an absolute dollar amount. However, this metric showed little consistency. Possibly this is due to an income effect where those with larger income have a higher value of time. Also, those with higher income tended to buy more expensive vehicles. Consequently a percent of full vehicle value was used as the metric.

As Figure 3 shows, seven out of nine one-vehicle households found no value in a vehicle that had only one station optimally placed near their home.

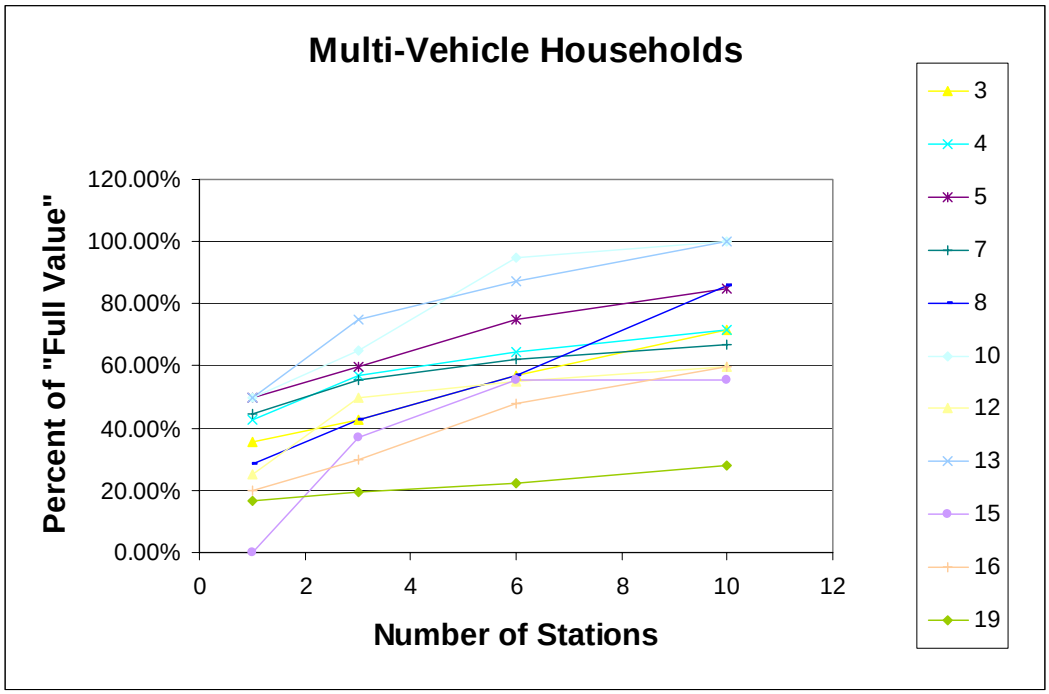

Figure 4: Percent of full vehicle value for multi- vehicle households as a function of the number of user defined stations. The networks evaluated were 1, 3, 6, and 10 station networks defined by the user. Each line represents a respondent.

This value reflects the fact that one-vehicle households (who stated that their next vehicle purchase was a replacement for their current vehicle) could not simply increase the size of their fleet by simply "getting a free alternative fuel vehicle". They had to make the decision whether or not to live with one vehicle that had only one station.

In contrast, multi-vehicle households had the option to use their gasoline vehicles when the alternative fuel vehicle did not meet their needs. This option is presumably why the vehicle values for multi-vehicle households in a one station network are greater (Figure 4) than for one-vehicle households.

The contrast between the multi-vehicle and single vehicle households can be seen in a boxplot in Figure 5. The results are separated into quartiles or roughly equal numbers of respondents. The shaded region in the middle represents 50% of the respondents. The black line represents the median value. The areas above and below the shaded region represent the other quartiles. In general we can see two features of the data. The range of values tends to be larger with the one-vehicle households and the median vehicle value tends to be lower as compared with multi-vehicle households.

One possible explanation of the wider range of values for one-vehicle households is that the lack of range has a much greater bearing on some individuals based on their situation. For example, some may have family far away necessitating a greater network whereas others may have simply only local travel needs. In contrast, the lack of range would have less bearing on multi-vehicle households since a gasoline vehicle could be used to accommodate longer trips.

4.3 Refuelling Locations

As with the activity spaces, the locations that respondents placed stations showed some commonality, and some differences. An intensity map is shown in Figure 6. The intensity map represents the overlap of station placements by respondents (excluding the "home" station). Only Davis residents are represented in Figure 6 in order to show an example of the needs for an external network. The marginal value of a station was calculated in terms of how much it affected the purchase price of the vehicle. In this way, unimportant stations were not reflected in the

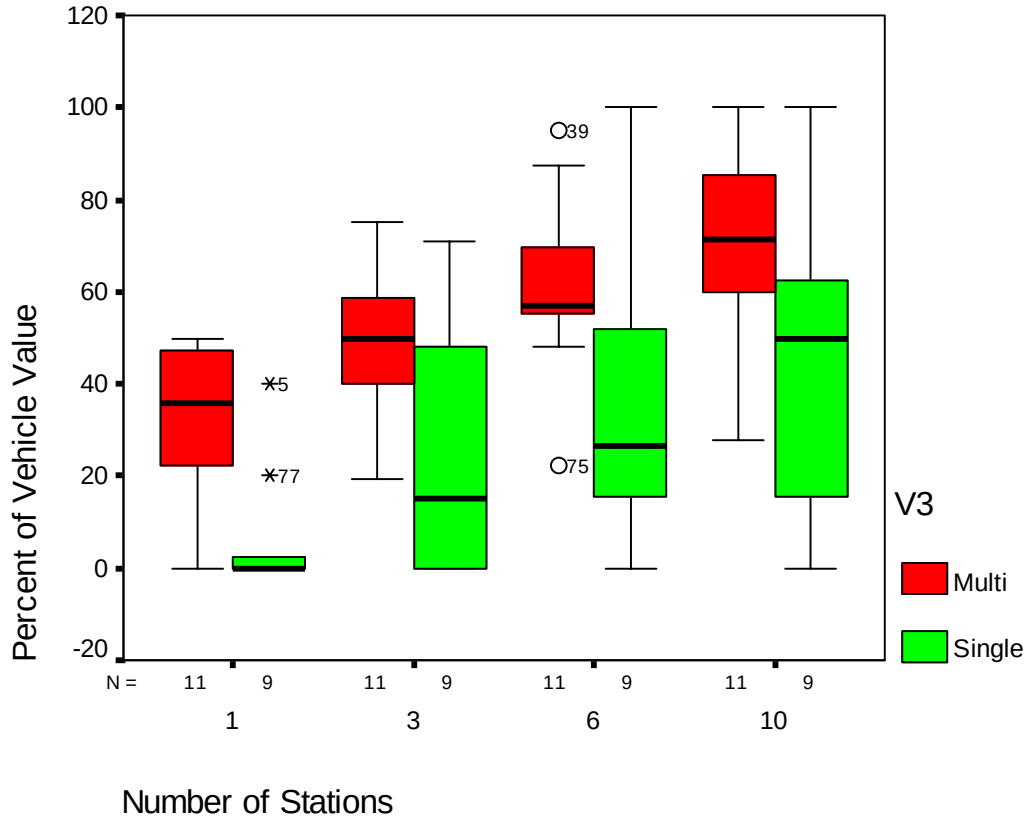

Figure 5: Boxplot representing showing the difference in value for multi and single-vehicle households of the four networks tested: 1, 3, 6, and 10 stations.

intensity. The influence of a station is highest at the station and decreases in value with distance up to 30 kilometers (20 miles). The 30 kilometer cut-off somewhat arbitrary but is based on the fact that even if a station is not exactly where a respondent placed it, the station may have similar value if it is near their choice, but that value decreases with distance. The highest intensity areas show up in yellow. Looking at the map, access in the towns surrounding Davis, and access in the San Francisco Bay Area (region southwest of the black dot) are the most important regions for refuelling. Also notable is the desire for fuel in Tahoe (area east of the black dot), and in the Los Angeles Area (southernmost red region). The importance of these areas suggests a few conclusions. First, that nearby large metropolitan areas are the most important for refuelling coverage. Second, that fuel availability in popular weekend locations has a significant effect on vehicle value. Third, availability in far away metropolitan areas has an effect on vehicle value, albeit less than for closer destinations.

The station choices can also be generalized in terms of distance from home (Figure 7). As indicated by the median values in Figure 7, the most important station is the closest, and for the first five stations, the importance decreases as distance increases. Stations six through ten are generally farther away than the first five stations, but the distance does not increase ordinally. These results suggest nothing surprising for the first five stations, simply that respondents expand their network in a rational fashion where closer locations are more important than locations farther away. The median value for the second station is 84km (52mi) and the median value for the third station is 93km (58mi). However large range of distances in locations six through ten indicate either that some respondents are filling in holes in their network to provide better coverage, while some are expanding their network to reach locations farther away.

4.4 Survey Limitations

The main limitation of the survey method is the online map interface. Although a computer map

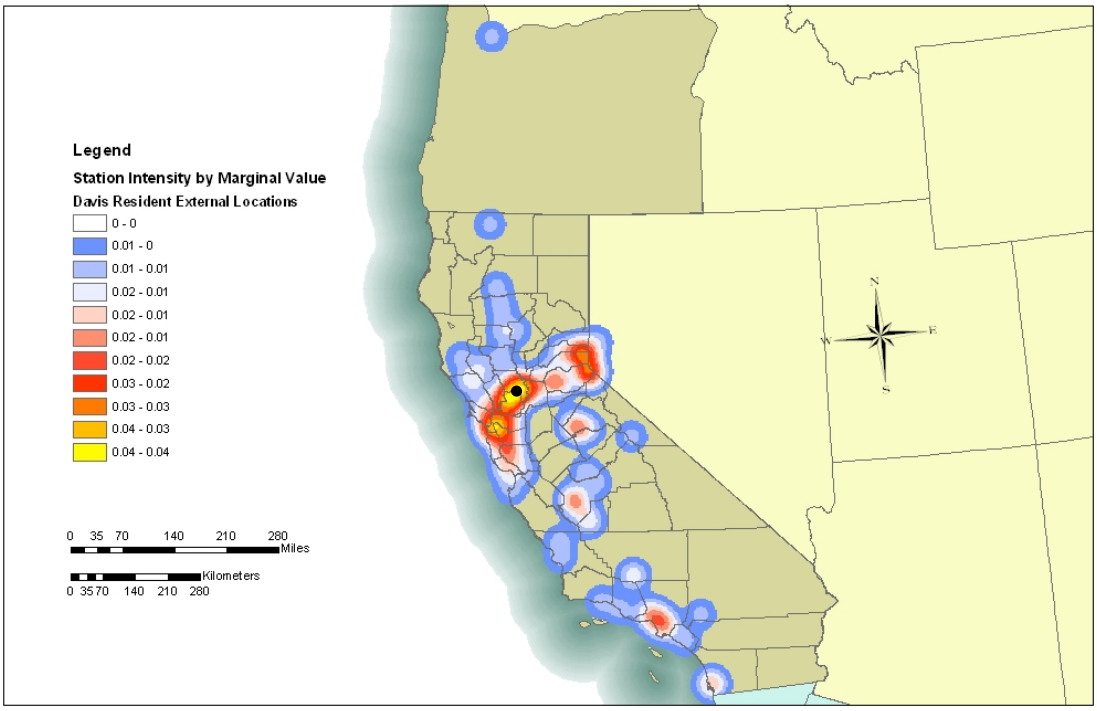

Figure 6: Station intensity by marginal value for Davis residents only. Davis is denoted by the black dot.

interface was designed, the paper maps were much easier for the respondents to examine their activity spaces easily, make corrections, place stations accurately etc. However, even with the paper map interface, some respondents simply didn't like maps, and claimed to be "horrible at them". Complicating the task with a computer interface may compound the problem.

Having to conduct the survey using paper maps is labor intensive and therefore not easily scalable. Several strategies can be employed to make the online mapping interface easier to complete, and therefore get a greater acceptance among respondents. Future versions of this survey method could focus on this aspect.

More generally, people are notoriously unreliable in stated preference surveys about refuelling availability. The first problem is that most respondents don't have any experience with limited refuelling. Additionally, there are no monetary consequences for the survey choices. In other words, people don't have to pay for a vehicle at the conclusion of the survey based on their responses. If there were a monetary consequence, some responses might change.

5 Preliminary Conclusions

As the results depend on a pre-test with a small sample size, strong conclusions cannot be drawn from this survey. Nevertheless, some preliminary conclusions can be made should this small sample represent a larger group.

The most obvious result is that multi-vehicle households find a much greater value in a vehicle as compared to those in one-vehicle households. For example, if an alternative fuel were only available near one's home, a vehicle only retains 20% to 50% of its value compared to a gasoline vehicle. Most one-vehicle households would not accept a free vehicle given these constraints if they had to trade their gasoline vehicle for the alternative fuel vehicle. For ten station networks in which travel throughout one's activity space is enabled, the alternative fuel vehicle retains 55% to 100% of its value for multi-vehicle households. The corresponding values for one-vehicle households is 0% to 100%.

One important indication from the survey is that frequency of visiting a station is not directly proportional to its value. Infrequently visited weekend destinations had a noticeable effect on the initial attractiveness of a vehicle.

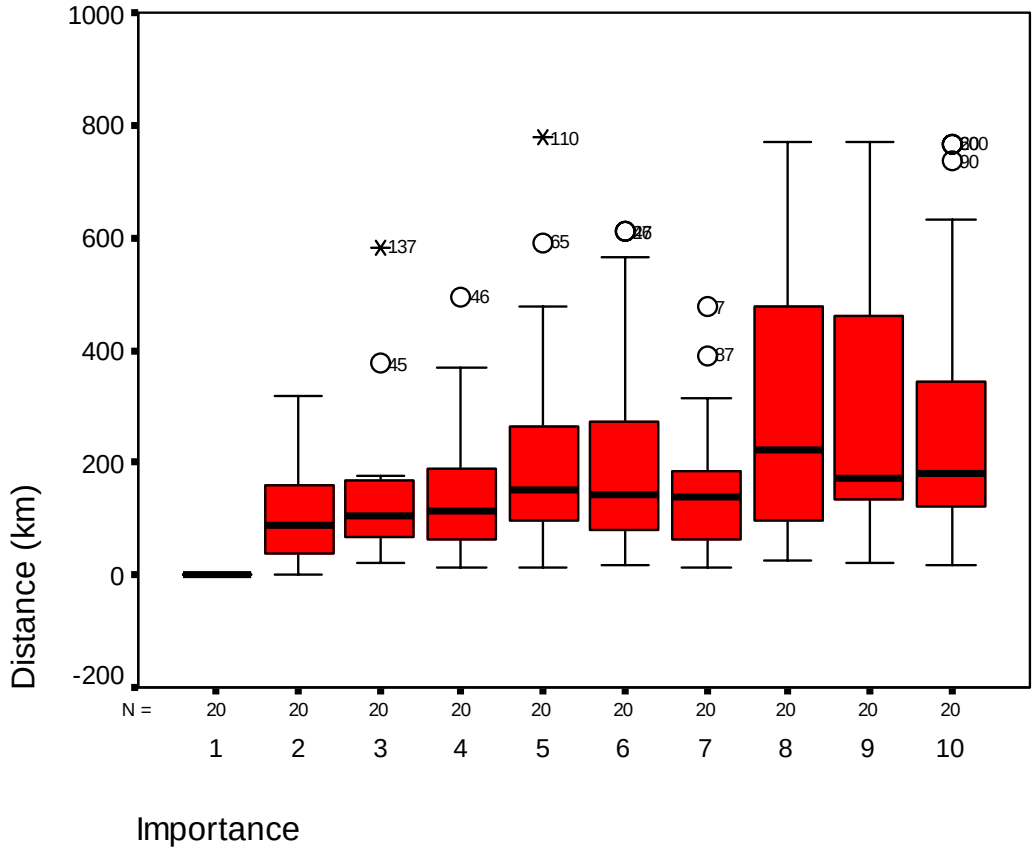

Figure 7: Distance vs. station importance. The numbers one through ten indicate the ordinal importance of a station. The black lines are the median distances for the respondents.

This survey provides some guidance for regionally focused introductions of alternative fuel vehicles. A uniform percentage of stations is not needed across an entire country or state. Metropolitan areas nearby the area of introduction are important, but market saturation of those areas is not needed. Popular weekend vacation locations are probably important to cover regardless of the frequency of use.

Lastly, this survey puts into context the previous estimates of station density based on the percentage of stations needed. 10 stations represents only 0.1% of stations in California. Yet at this level, multi-vehicle households were willing to pay 55%-100% of the price of a comparable gasoline vehicle. Station networks will have to be designed to accommodate more than one user, but the survey suggests that a well designed sparse network could serve a large number of users if introductions of vehicles are geographically focussed.

Acknowledgments

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References

1 Segal, Robin. 1995. Forecasting the Market for Electric Vehicles in California Using Conjoint Analysis. *The Energy Journal* 16, no. 3: 89-111.

2 Greene, David. 1998. Survey Evidence on the Importance of Fuel Availability to the Choice of Alternative Fuels and Vehicles. *Energy Studies Review* 8, no. 3: 215-231.

3 Bunch, David S., Mark Bradley, Thomas F. Golob, Ryuichi Kitamura, and Gareth P. Occhiuzzo. 1993. Demand for Clean-Fuel Vehicles in California: A Discrete-Choice

Stated Preference Pilot Project. *Transportation Research Part A: Policy and Practice* 27, no. 3: 237-253.

4 Bureau of Economic Analysis. 2009. *National Income and Products Accounts Table*. Accessed April 1 2009. Available from http://www.bea.gov/national/nipaweb/TableView.asp?SelectedTable=28&ViewSeries=NO&Java=no&Request3Place=N&3Place=N&FromView=YES&Freq=Year&FirstYear=1990&LastYear=2008&3Place=N&Update=Update&JavaBox=no#Mid.

5 Kurani, Kenneth S and Thomas S. Turrentine. 2002. Household Adaptations to New Personal Transport Options: Constraints and Opportunities in Household Activity Spaces. In *Perpetual Motion: Travel Behevior Research Opportunities and Application Challenges*, ed. H.S. Mahmassani: Elsevier Science Ltd., Chapter 3.

6 Kurani, Kenneth S., Thomas Turrentine, and Daniel Sperling. 1996. Testing Electric Vehicle Demand in 'Hybrid Households' Using a Reflexive Survey. *Transportation Research Part D: Transport and Environment* 1, no. 2: 131-150.

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