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ELECTRIC VEHICLE PURCHASING INTENTIONS: THE CONCERN OVER BATTERY CHARGE DURATION

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Abstract—Exploratory research has been conducted to assess the relative importance of the factors which are most influential in discouraging the purchase of an electric car. In addition, trade-offs among the following factors: range, maximum speed, recharging time, and cost/delay in the case of a battery rundown, are estimated. Results point to a gap in the growing extant literature with respect to the high relative importance of the problems associated with a possible dead battery and that potential buyers may find these problems unacceptable, as is the case with problems associated with limited range and/or speed. The differentiation of preferences is examined with respect to socio-economic and demographic variables. The percentage of participants preferring a specific electric car concept is also compared with its average probability of being purchased.

1. INTRODUCTION

Although the battery-powered electric car is seen by many legislators and environmental groups as the solution to traffic-triggered air pollution, it is not yet obvious how much convenience drivers are ready to sacrifice, nor the price premium they are willing to pay for an electric car. As several studies have already stressed, there is little enthusiasm amongst potential purchasers for a car that costs more than a conventional one, has a limited range and speed, and needs a lot of time to be recharged. The present research reveals the presence of a much more dramatic factor which is blocking the desire to purchase an electric-powered car: the fear of a power failure owing to a dead battery. This factor has been overlooked in all previous research reviewed. The original open-ended methodology used in this research enabled the emergence of this particular dimension.

2. THE ISSUE

Although there have been many electric car projects over the years at differing levels of competition, the recent move by California to introduce tough legislation (requiring 2% of car manufacturers' yearly revenues to be generated from the sale of zero-emission vehicles by 1998, and up to 10% by 2003) has triggered new curiosity and led to questioning of the viability of such a requirement. A dozen other states are expected to follow California's lead shortly (O'Connor, 1993; Tyler, 1994; Taylor, 1993, 1994).

Electric vehicles, which were ahead of gasoline-powered vehicles in the early ages of automobiles, lost the battle and vanished for decades primarily because of limited range and speed. Everybody appears to acknowledge that electric vehicles will restrict driving time and range as well as speed. Recharging time will be long and the purchase price will generally be higher than that of a conventional car. Can such a requirement thus be realistically imposed upon the consumer?

Recent efforts by engineers are trying to push back the limitations: more autonomy, higher speed, lower cost of purchase and battery replacement. But how much improvement will be required to attract enough customers to lead to the existence of a viable market for electrical vehicles? The specific issue addressed in this research is to determine if there is a chance that an electric vehicle would be bought by a family in full knowledge of its limitations.

The major problem of electric vehicles lies in the limitations of batteries: weight, cost, limited charging capacity which allows for only a short driving range, and a long recharging time (battery recharges imply plugging the car into the regular electrical power network at home, or wherever accessible). Potential buyers will probably be reluctant to pay more for a car with such limitations. But will consumers trade off these limitations in exchange for lower pollution levels, less noise, and a very low cost of recharging the battery?

3. THE PRESENT STATE OF THE RESEARCH

Research, current and previous, has made it clear that only a minority of consumers was ready to pay a premium to reduce pollution. Moreover, limited driving range, or autonomy time, and poor performance in addition to its small size seemed to position the electric car, at best, as a second car for city use. If production levels allow it to be manufactured at a price closer to that of a regular car, the low cost of use becomes an attractive feature.

Recent research also shows that for a significant number of consumers, a 90 mile range could be acceptable, especially if considering the case of a second car in a two (or more) car household (Sperling, 1994; Turrentine and Sperling, 1991).

Past studies on travel behavior or constraints analyses (Kiselewich and Hamilton, 1982; Deshpande, 1984; Nesbitt *et al.*, 1991) focusing on the issue of limited range generally conclude that the limited range of electrical vehicles is perfectly suitable to the driving habits of most households (over 80%) and can furthermore satisfy most of the trips made. Attitude (Buist, 1993; Kirchman, 1993; Fairbanks Maulin and Associates, 1993; Turrentine *et al.*, 1992) surveys reveal also that the electric option receives good attitude scores because of its clean and technological image. However, it is well known that many obstacles can interfere between attitude and purchase, e.g. situational or psychological factors. Some other studies have asked consumers to state preferences or buying intentions for different vehicle concepts, and have derived various utilities especially with respect to limited range. They conclude that limited range is an overwhelming drawback (Beggs and Cardell, 1980; Hensher, 1982; Calfee, 1985; Bunch *et al.*, 1991).

Recently, a new approach has been suggested. Instead of looking at a single purchase decision based on limited information, it looks at the global travel behavior of the household and how this reflects on the driving behavior and options for potential solutions in different situations. These Purchase Intentions and Range Estimation Games (PIREG) approaches are based on the Car Use Patterns Interview Games (CUPIG) developed by Lee-Gosselin (1990). The solution, therefore, seems to lie in a hybrid fleet and the optimization problem for consumers addresses range and recharging time, and the choice of which vehicle to use: either electric or gasoline-powered (Kurani *et al.*, 1994).

Urban *et al.* (1996) have recently tested a new information acceleration (IA) method where consumers are placed in a virtual buying environment simulating the information available to the consumer at the time a purchase decision of an electric vehicle is made. They conducted two studies to estimate sales forecast under various future conditioning. In both studies they used a popular internal combustion engine as a control vehicle to estimate the biased introduced by the IA laboratory. When new technologies are involved, consumer learning is required and the use of a conventional vehicle as a benchmark is necessary.

Most of these studies take the issues and variables studied for granted and put consumers in front of a predetermined optimization problem. But does the consumer really think this way? Does he or she really decide this way?

4. RESEARCH OBJECTIVES

The present research was conducted in order to determine:

1. Which are the most determinant factors in blocking the purchase of an electric vehicle?
2. Are there any possible trade-offs?

5. RESEARCH METHODOLOGY

Four groups of car users were recruited during the month of July 1994 in Montreal. The groups were balanced in terms of socio-demographic variables and high or low mileage needs per week. People involved with the automobile industry, such as car dealers or car salespersons, were excluded. The procedure for each group consisted of three phases and the whole process took about two hours per group.

In the first phase, the moderator and participants introduced themselves and each participant in turn talked about his daily reasons for using a car. Then, the participants were asked about the relative importance of their car expenses. Discussions were unstructured and conducted in a brainstorming fashion, about expectations, satisfactions, fears and perceived risk when using their present vehicle. They were then introduced to the concept of an electric vehicle and asked about awareness, a priori perceptions, and required information. Each participant was handed a written description of the present concept of an electric vehicle as shown in Appendix A.

The second phase consisted of discussion focused on a specific question related to the Electric Car Concept. The Nominal Group Technique (NGT) was used (Delbecq *et al.*, 1975). NGT is designed to increase creativity and participation and to reach an aggregate importance ordering of the ideas generated by the group. The following question was submitted in writing and read verbally to each group:

> "In your opinion what are the problems related to using an electric car that would turn off a potential buyer?"

The NGT procedure consists of six steps:

1. Silent generation of ideas in writing. This step is designed to maximize creativity, to facilitate hard work, to avoid interruption by other participants, to eliminate dominance by some members and to keep the group problem-centered.
2. Round-robin recording of ideas on a flip-chart. Each idea is serially recorded in the words used by the group members. Members decide if items are duplicates and they may 'pass' when they have no further items to add but may 're-enter' later. The entire list is made visible to all group members by tearing off completed sheets and taping them on an area that is visible to all group members.
3. Serial discussion for clarification. The objective of this step is to classify the meaning of items and to explain reasons for agreement or disagreement. The benefits of this step are to eliminate misunderstanding and to express the logic behind items.
4. Preliminary vote on item importance. The group is asked to select the seven most important items from the entire list. Each participant indicates his choice of the seven items on a preliminary voting form. The forms are collected and choices are tallied on the entire list, visible to all participants.
5. Discussion of preliminary vote. A short discussion follows the frequency count to make sure each participant understands the preliminary order of importance. This step allows participants to clarify their positions and to ensure that divergent votes really reflect differences in judgment and not unequal information or misunderstanding.
6. Final vote. Each participant is asked to select the five most important items from the entire list and to give an importance rating of 1 to 10 (where 10 is most important) to each of the five selected items. The five selected items and associated ratings are indicated by each participant on a final voting form. The objective of this final step is to generate a more accurate ordering of group judgments.

The third phase of each group meeting was conducted in a separate room where participants were asked to complete a conjoint analysis task and to complete a short questionnaire. The conjoint analysis procedure consisted of an experimental design combining the four most important variables emerging from the NGT procedure, each at three levels:

1. Range (100 km, 200 km, 300 km);
2. Maximum speed (70 km/h, 100 km/h, 120 km/h);

3. Recharging time (4 h, 6 h, 8 h);
4. Cost and delay in case of a dead battery (1/2 h and \$20, 2 h and \$100, 4 h and \$200).

The complete design amounted to: $3\times3\times3\times3=81$ profiles. The task of ordering 81 profiles is unreasonable. Therefore, a fractional orthogonal design of nine profiles (a Latin square design) was generated using the SPSS software orthoplan procedure.

In addition to the nine orthogonal profiles, three holdout profiles were generated to check the predictive validity of the model for each respondent. The ordering task of each participant was therefore limited to 12 profiles. An example of a profile is presented in Appendix B. After ordering the 12 profiles, participants were asked to trace a diagonal line over the profiles that they found unacceptable.

A final short questionnaire, consisting of two parts, was administered to the group members. In the first part, participants indicated for each variable, the level or levels they found unacceptable. Then they were asked to allocate 100% among the four variables according to their personal judgment of relative importance. Finally, the probability of buying the best (range of 300 km, maximum speed of 120 km/h, charging time of 4 h, cost and delay of 1/2 h and \$20 in case of a battery runout) and the worst profile of an electric car were measured. The second and last part of the questionnaire consisted of questions related to socio-demographic variables.

This approach allowed us to start from a 'blank sheet' and to generate the true feelings of car owners, who in previous studies were led to evaluate dimensions already predetermined by researchers.

6. RESULTS

Two groups included 10 participants, one group included nine and the last one included eight for a total of 37 respondents. Males accounted for 65%, respondents driving more than 200 km per week for 51%, 59% had a college degree, the average age was 50 yr and 49% had an average revenue above \$35,000. The first phase of the group discussion revealed that participants used their present vehicle to go to work, for grocery shopping and for leisure activities. Women used the car also to drive children to school or to playgrounds. Monthly payments for financing the car and gas expenses were taken into account in the participants' budgets. However, most participants had no budget to meet repairs and maintenance on their car. As a result, 34 participants out of 37 had no idea of the total amount they spend per year on their car.

Expectancies with the present vehicle were mentioned in the following order: comfort (22 participants), reliability (13), durability (10), power (10), road handling (9), safety (7), economy (7), fair price of parts (5), etc. After comfort, participants expected a car to be reliable, meaning a car that can be counted on to start up every morning, especially during the winter season.

In terms of fears and perceived risk with their present vehicle, participants indicated the following items: being out of gas out of town or in a deserted or dangerous area (15 participants), having an accident (10), a mechanical breakdown far from a garage (5), not being able to start up in the morning and/or in the winter season (4), being stuck in a traffic jam (3), having a flat tire during the winter season (1), etc. Therefore, the most frequent fears are: being out of gas, followed by having an accident and having a mechanical breakdown.

When introduced *a priori* to the concept of an electric vehicle, most participants said that they had a vague idea of what was involved. When asked about their thoughts, the following ideas were mentioned: a more expensive car, a smaller and less comfortable car, a slower car, a car with a wire (for connection), a car recharging while running, an ecological car, a car in need of frequent recharge, a car with limited range, a less reliable car, a less safe car, a golf cart, a low-performance car, a city car (a second car for short distances), a self-recharging car using solar energy, a less noisy car, a car that does not work during the winter season.

After being formally introduced to the concept of an electric car, verbally and in writing (see Appendix A), participants were asked if they had further questions about the concept. The main questions were the following: How far can we go (range)? When driving fast, is the range lower? Where can we recharge? Apart from the engine, is the maintenance similar? How many and where will the service stations be? Is it reliable for start up in winter? How do you connect the car when

Table 1. Aggregate list of problems generated by 37 participants

Item	Total rating	Average rating
Dead battery	287	287/31 = 9.26
Recharging time	228.5	228.5/26 = 8.79
Range	209	209/24 = 8.71
Performance	186	186/23 = 8.09
Battery cost	156	156/18 = 8.67
Cost of the vehicle	146	146/18 = 8.11
Availability of an electric plug	95	95/12 = 7.92
Impact of accessories on efficiency	62	62/7 = 8.86
Uncertainty of possible savings	48	48/5 = 9.60
Safety	40	40/4 = 10.0
Maintenance/after sales service	26	26/4 = 6.50
Need to plan recharging	23	23/3 = 7.67
Reduced roominess	22	22/3 = 7.33
Sturdiness	19	19/2 = 9.50
Cost of service for battery runout	10	10/1 = 10.0
Need to own two cars	9	9/1 = 9.00

you live in an apartment? Is an explosion possible in case of an accident? Are the savings on gas equivalent to the cost of the battery? Is it possible to have a spare battery? Most questions and uncertainties were related to the range of an electric car, how to recharge at home, and on-the-road maintenance, reliability, safety and economy.

The following step was the NGT procedure designed to generate a maximum number of problems related to using an electric car. In addition to the list of problems, participants individually classified and rated the problems in order of importance. The list of problems and importance scores were generated for each of the four groups. The consolidated list, in decreasing order of importance, appears in Table 1.

As shown in Table 1, the risk of a dead battery was perceived by participants as the most important item, with a total rating of 287. Since this item was selected by 31 participants out of 37, the average rating is 9.26. The second, third and fourth items in decreasing order of importance were: recharging time, range and performance. Some items such as safety, cost of service for battery runout and sturdiness were associated with high average ratings, but this should be put into perspective by taking into account that these items were selected by fewer than five respondents.

The third phase was the conjoint analysis task of ordering nine orthogonal profiles and three holdout profiles (for an example see Appendix B). In addition, participants indicated the profiles that they found unacceptable.

Table 2 indicates the relative importance of the four variables retained for the conjoint analysis. The partial utilities of the four variables were first estimated for each respondent individually. A linear regression model was used with the nine orthogonal profiles as dummy independent variables and the rank order as the dependent variable. Carmone *et al.* (1978) have reported Monté Carlo results showing that metric methods applied to ordinal data in conjoint analysis were equivalent to nonmetric approaches. Ranges of partial utilities relative to total range were used as a measure of relative importance of each of the four variables for each respondent. Relative importance was then aggregated over the 37 participants. The internal validity of the model was

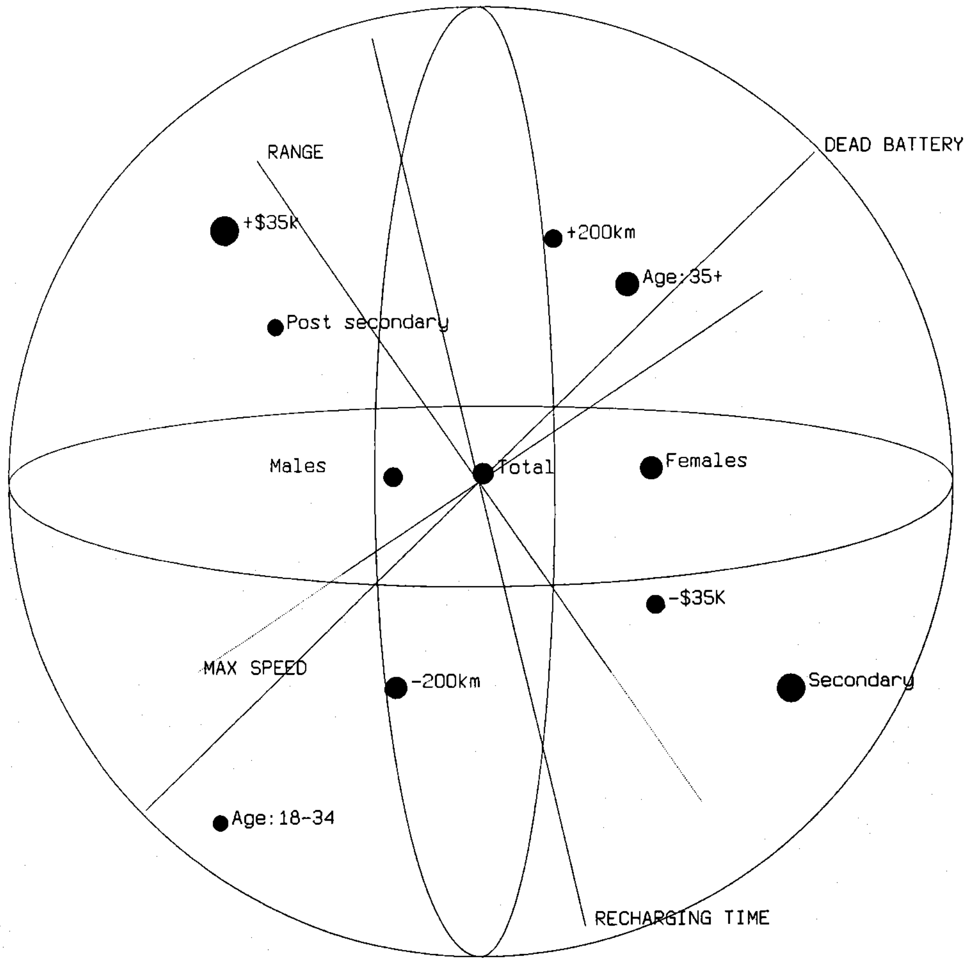
Table 2. Relative importance of the four variables with conjoint task

Variable	Relative importance over 37 respondents (%)	Relative importance over 20 internally valid respondents (%)	Relative importance from direct allocation of 100% (%)
Delay and in case of a dead battery	36.15	39.89	23.43
Maximum speed	26.50	28.52	22.57
Range	25.04	22.95	37.03
Recharging time	12.31	8.64	16.97

examined for each participant using the Tau correlation coefficient between the predicted and the observed ordering of the holdout profiles. All participants with Tau values less than 0.5 were excluded and a new aggregate relative importance was computed over 20 participants. Finally, the relative importance was obtained from the direct allocation by respondents of 100% to each of the four variables.

Results in Table 2 indicate that, in the conjoint task, participants tend to attribute more relative importance to delay and cost in case of a dead battery. This is also confirmed when only internally valid respondents are retained. However, when respondents were asked directly for their perceived relative importance, range turned out to be the most important variable followed by the dead battery problem and maximum speed. This difference in results may be due to the different task involved when each respondent is rank ordering the 12 profiles as opposed to directly allocating 100% to four attributes in terms of relative importance.

Using the conjoint results and the participants' categories allowed for the preparation of a multivariate tridimensional representation of the data. This multivariate graphical representation is an efficient three-dimensional procedure relaxing the usual orthogonal orientation of the axes of the variables. Figure 1 is a tridimensional representation of subgroups of participants in relation to the four variables. The graph must be seen in perspective with large points in the foreground (e.g. females and secondary education) and small points (e.g. males and post secondary education) in



Total variance accounted for:
In one dimension 56.083%
In two dimensions 84.812%
In three dimensions 99.971%

Fig. 1. Differentiation of preferences.

compensated through trade-offs, because it represents a disjunctive cut-off factor leading to the rejection of the option for most car owners.

These issues, and the results of this research, will require more analysis and further research. Research is needed in the following areas:

1. How much can the second car status in an urban setting do to diminish the concern over battery charge duration?
2. Would a hybrid car with an emergency motor (like a sail boat with a motor) be acceptable?
3. To what extent would an increased range would reduce the perceived risk?
4. Why was the issue of air conditioning and heating not raised by the respondents as a trade-off for range?
5. How extensive should the recharging networks be to reassure the electric car owner?

Moreover, most previous research should be considered by keeping in mind that some hidden factors could affect the decision process of car owners and their perception of electric cars. Appropriate research methodologies, such as the NGT procedure used in this study, should allow the emergence of such factors.

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—Appendix A overleaf

Table 3. Number of participants out of 37 finding the level unacceptable

Range:	100 km	32
	200 km	8
	30 km	5
Maximum speed:	70 km/h	33
	100 km/h	4
	120 km/h	5
Recharging time:	4 h	6
	6 h	7
	8 h	27
Dead battery problem:	1/2 h, $20	6
	2 h, $100	7
	4 h, $200	32

the background. The variables are represented by oriented vectors passing through the center of the sphere. The position of the label indicates the positive orientation of the variable. The angle formed by two vectors indicates the degree of correlation between two variables. Hence, range is negatively correlated (−0.59) with recharging time, reflecting the perception by respondents that more range requires more recharging time. Maximum speed is also perceived to be negatively correlated (−0.79) with the risk of a dead battery since fast driving is likely to use up the battery more quickly. The orthogonal projections of points on each vector give the ordering of subgroups with respect to the corresponding variable. For instance, maximum speed has more relative importance for 18–34 yr-old respondents and less relative importance for those over 35 years old. Further examination of Fig. 1 indicates that range is more important for participants with annual revenues above $35,000 and with post secondary education. The relative importance of the dead battery problem is higher for respondents 35 years old and over, for those driving more than 200 km per week and for females.

Concerning the unacceptable variable profiles, 29 respondents out of 37 found the most defavorable profile (range: 100 km; max speed: 70 km/h; recharging time: 8 h; dead battery problem: 4 h and $200) unacceptable. However, the most favorable profile (range: 300 km; max speed: 100 km/h; recharging time: 6 h; dead battery problem: 1/2 h and $20) was found unacceptable by only two respondents out of 37.

With respect to each level of each variable, Table 3 indicates the number of participants finding the level unacceptable. Results in Table 3 confirm the high proportion (29 out of 37) of respondents finding the former defavorable profile to be unacceptable. The best profile used as a simulated product concept was estimated to be preferred by 97% of the participants.

Respondents were also asked the probability of buying the best profile when they acquire a new vehicle in the future. The average probability of buying was only 49% for all respondents together. This difference between preference and buying intention is not unusual. Urban *et al.* (1996) find that a reported 53% purchase intention reduces to 25% once movements towards substitutes is taken into account. Further research could also explore the possibility of buying an electric vehicle as a second car rather than as a replacement for the main vehicle of the household.

7. CONCLUSIONS AND IMPLICATIONS

Whatever the methodological constraints and limitations of this research, the results point in one direction: the concern over battery charge duration, more than anything else, will prevent the acceptance of the electric car by the market.

The perceived risk is too high on a dimension that is, on a par with an accident, the most dreaded event: a breakdown, running out of 'energy' on a highway, in a risky situation (such as at night in the rain) and having to spend hours and hundred of dollars in towing and recharging costs to get going again. So, unless the driving range is increased significantly, and recharging is faster and easily accessible, it is difficult to envision broad consumer acceptance of electric cars.

Our research finds that this factor can hardly be compensated by savings or cleanliness. Previous research focused only on very rational dimensions which are range and performance. Behind the rationality of the range and performance factor lies the fear of a dead battery which cannot be

APPENDIX A: THE ELECTRIC CAR—DESCRIPTION SHEET

Global appearance

About the same models as are currently available for gas will be offered in electric version.

Capacity

The load capacity and storage space will be slightly reduced to accommodate the batteries.

Speed and performance

The maximum speed can vary from 70 to 120 km/h for different types of vehicle. This speed takes slightly longer to achieve than for a gas-powered vehicle.

Pollution

(a) No noise.

(b) No harmful emissions.

Safety

Safety is the same in an electric vehicle as in a gas-powered vehicle.

Range

From 100 to 300 km according to the vehicle, on the highway and a speed approaching the maximum.

Battery recharge

Batteries can be recharged by connecting the vehicle into an ordinary domestic electric outlet, like a motor heater.

Delay for recharging an almost empty battery varies from 4 to 8 h.

Emergency service

In case the vehicle runs out of power, when driving beyond the maximum range, it must be brought to a specialized service station at a distance which may vary according to the spread of the service network.

A special high-voltage recharging system is available in some garages and reduces the recharging time to 30 min.

Cost of purchase

From $4000 to $6000 more than for an equivalent gas-powered vehicle.

Recharging cost

This vehicle's motor has no maintenance cost. The operation is about $0.75/100 km compared with $5–6/km for a gas-powered vehicle, about 10 times cheaper.

Battery replacement

Approximate lifetime of three years, replacement cost: $3000.

APPENDIX B: EXAMPLE OF ONE PROFILE USED FOR THE CONJOINT TASK

Range 200 km	
Maximum speed	100 km/h
Recharging time at home	4 h (complete recharge)
Delay and cost in case of a dead battery	4 h and $200