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Electric vehicles in multi-vehicle households

Michael A. Tamor *, Miloš Milačić

Research and Advanced Engineering, 2101 Ford Motor Company, Village Road MD-1170, Dearborn, MI 48121, United States

A R T I C L E I N F O

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A B S T R A C T

The suitability of an electric vehicle of a given range to serve in place of a given conventional vehicle is not limited by the daily travel over distances within that that range, but rather by the occasional inconvenience of finding alternative transport for longer trips. While the frequency of this inconvenience can be computed from usage data, the willingness of individual users to accept that replacement depends on details of available transportation alternatives and their willingness to use them. The latter can be difficult to assess. Fortunately, 65% of US households have access to the most convenient alternative possible: a second car. In this paper we describe an analysis of prospective EV acceptance and travel electrification in two-car households in the Puget Sound region. We find that EVs with 60 miles of useful range could be acceptable (i.e. incur inconvenience no more than three days each year) to nearly 90% of two-car households and electrify nearly 55% of travel in those households (32% of all travel). This compares to 120 miles range required to achieve the same fraction of electrified travel via one-for-one replacement of individual vehicles. Even though only one third of personal vehicles in the US may be replaced in this paradigm, the 'EV as a second-car' concept is attractive in that a significant fraction of travel can be electrified by vehicles with modest electric range and virtually no dependence on public charging infrastructure.

1. Introduction

In order to achieve broad acceptance, all-electric vehicles (EV) must offer customers an attractive economic proposition relative to a conventional vehicle (CV). While doing so, they must not impose an unacceptable level of the inconvenience of finding alternative transportation for journeys beyond EV range or along which charging is unavailable. Until battery and charging technology evolve to enable at least 300 miles of all-weather range at a very low per-kilowatt-hour battery cost and extremely fast recharging at convenient locations – in short, all the convenience of a CV – these criteria will be in conflict. While it is straightforward to model the total-cost-of-ownership (TCO) of electric vehicles, it is far more difficult to predict tolerance for inconvenience. Several studies of real-world vehicle usage have estimated the frequency of 'range inconvenience' when substituting an EV for a given conventional vehicle, and find that for most users a realistic 100 mile range (EV100) is inadequate sufficiently often (on more than six occasions per year) that their willingness to accept such an EV may be doubtful unless a very convenient alternative is available (Pearre et al., 2011; Khan and Kockelman, 2012; Tamor et al., 2013). Tamor et al. (2013) assumed a single common threshold for inconvenience and a simple six-year payback model to show that while an optimal range for EV can be found (150–200 miles for the Minnesota drivers in that study), batteries must be unrealistically cheap (less than $100/kW h) to achieve meaningful market penetration. However, tolerance

* Corresponding author. Tel.: +1 313 337 4108; fax: +1 313 594 2963.
E-mail addresses: mtamor@ford.com (M.A. Tamor), mmilacic@ford.com (M. Milačić).

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for 'range inconvenience' is an individual characteristic that has a physical component (the transportation options available to an individual) and an emotional component (the tolerance for the disruption in using those options), and so is very difficult to quantify.

The 'range inconvenience' question has been addressed in two ways: (1) surveys of prospective owners of alternative vehicles, and (2) analyses of actual vehicle usage that posit a penalty for the inconvenience of charging away from home or finding alternative transportation. In surveys, Axsen and Kurani (2013) found very limited acceptance of EV even when a 150 mile range was offered at cost parity to a conventional vehicle. Similarly, Daziano (2013) found that respondents viewed 330 miles as necessary to achieve functional parity with CV (all else being equal including cost) and very little willingness to pay a realistic price for EV range over 50 miles even though most daily needs were modest. In contrast, participants in an early market test of the 105 mile-range BMW Mini-E reported easy adaptation to its range limitations and very little need for charging away from home (Turrentine et al., 2011). In analyzing usage studies, the inconvenience penalty can take two forms: the simple assumption that a vehicle that causes inconvenience too often will be rejected outright (the 'threshold' method as in Tamor et al., 2014) or that the cost of ownership becomes unacceptable when a monetary cost for charging and alternative transportation is included. In a recent study seeking an optimal EV range (that minimizes cost of ownership) for individual users, Lin (2014) imposed a $50/day penalty for finding alternative transportation (plus the cost of that trip). He found that the resulting average optimal range of 85 miles was quite insensitive to a modest increase in the inconvenience penalty, but did not test the requirement that cost of ownership be less than that of a CV. Barter et al. (2015) compared the penalty and threshold approaches in modeling the adoption of a variety of alternative vehicles (EV, PHEV and natural-gas vehicles) as direct replacements for individual CV, and found while EV penetration always remained modest (at most 5%) the choice of electric range shifted slightly. They also found that battery cost must be reduced well below $200/kW h to drive a significant increase in EV penetration. This is consistent with the earlier findings of Delucchi and Lipman (2001) that electric vehicles of any plausible range could not compete directly with CV until battery cost decreased to roughly $100/kW h.

A simple way to avoid the complexities of the 'range inconvenience' question is to focus only on what is by far the most convenient and predictable alternative transportation mode: another vehicle in the same household. At present, this option is most ubiquitous in the United States where 65% of vehicle-owning households have more than one vehicle, and 82% of all vehicles are in multivehicle households (NHTS, 2009). Previous studies suggest that EV acceptance in multi-vehicle households (MVHH) could be high. Kurani et al. (1996) surveyed 454 MVHHs in California to estimate ability to adopt an electric vehicle and thereby become a 'hybrid household'. Based only on the household estimates of vehicle usage and other preferences, they estimated that EVs might account for 7–18% of private light-duty vehicle (LDV) sales in California. Khan and Kockelman (2012) analyzed real-word driving records from 255 vehicles in MVHH in the Seattle area. They found that under specific assumptions 80% of those households would be inconvenienced no more than roughly 3 times per year when substituting an EV100 for one household vehicle.

In this paper we compare three methods for estimating acceptability of EV in both single- and two-vehicle households, and propose a greatly simplified method for estimating the acceptance of EV in regions for which such detailed usage data is unavailable. First we use simple trip counting to analyze the same Seattle area driving data (PSRC, 2008) using actual one-day travel distances in all households including single-vehicle households (1VHH), and then the paired one-day travel distances in two-vehicle households (2VHH), similar to the analyses described by Khan and Kockelman (2012). Our results are similar, but not identical because we use a different logic for vehicle choice for each trip each day. Second, we adapt the five-parameter statistical description of individual daily distance-frequency distributions (Tamor et al., 2013 and Tamor et al., 2014) to describe pairs of vehicles in the same household. Because the individual trip distance distributions cannot capture the daily correlations between vehicles in the same household, the statistical method cannot be applied directly to 2VHH. To address this problem, we examine the correlations of the parameters that describe the one-day travel distance-frequency distributions for vehicles in the same household. These are found to be uncorrelated, which means the results should be identical if the vehicles were paired at random rather than with their house-mates. We confirm this hypothesis by randomizing the household pairs in the Puget Sound data and repeating the trip-counting analysis, with results essentially identical to those for properly paired vehicles. This is a huge simplification as it implies that 2VHH can be represented by random pairings of vehicles from a distribution that represents the overall population of a given region. Finally, by exploiting this lack of correlation, we derive a purely analytic estimate of EV acceptance in 2VHH that may be based on much sparser single-day usage data or even regional travel statistics.

2. Trip counting

The vehicle usage data used for this study was drawn from the Puget Sound Regional Council Traffic Choices Study (PSRC, 2008). This data is made available to the public by the National Renewable Energy Laboratory on the website of the Secure Transportation Data Project (NREL, 2013). The usage data for 446 vehicles (274 of which are in 137 two-vehicle households and 24 are in three-vehicle households) is available in the form of a list of trips (the travel from a key-on to key-off event) labeled by start and end time, and distance for each vehicle. [Actual GPS data is not needed for this type of analysis.] The distances of all the separate trips on a given calendar day were summed to create a list of total daily travel distance for each vehicle for each date (defined as 4 am to 4 am the next day) on which it was driven. Of the total travel in the data base, 33%