

Actual Versus Estimated Utility Factor of a Large Set of Privately Owned Chevrolet Volts

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ABSTRACT

In order to determine the overall fuel economy of a plug-in hybrid electric vehicle (PHEV), the amount of operation in charge depleting (CD) versus charge sustaining modes must be determined. Mode of operation is predominantly dependent on customer usage of the vehicle and is therefore highly variable. The utility factor (UF) concept was developed to quantify the distance a group of vehicles has traveled or may travel in CD mode. SAE J2841 presents a UF calculation method based on data collected from travel surveys of conventional vehicles. UF estimates have been used in a variety of areas, including the calculation of window sticker fuel economy, policy decisions, and vehicle design determination.

The EV Project, a plug-in electric vehicle charging infrastructure demonstration being conducted across the United States, provides the opportunity to determine the real-world UF of a large group of privately owned Chevrolet Volt extended range electric vehicles. Using data collected from Volts enrolled in The EV Project, this paper compares the real-world UF of two groups of Chevrolet Volts to estimated UF's based on J2841.

The actual observed fleet utility factors (FUF) for the MY2011/2012 and MY2013 Volt groups studied were observed to be 72% and 74%, respectively. Using the EPA CD ranges, the method prescribed by J2841 estimates a FUF of 65% and 68% for the MY2011/2012 and MY2013 Volt groups, respectively. Volt drivers achieved higher percentages of distance traveled in EV mode for two reasons. First, they had fewer long-distance travel days than drivers in the national travel survey referenced by J2841. Second, they charged more frequently than the J2841 assumption of once per day - drivers of Volts in this study averaged over 1.4 charging events per day. Although actual CD range varied widely as driving conditions varied, the average CD ranges for the two Volt groups studied matched the EPA CD range estimates, so CD range variation did not affect FUF results.

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INTRODUCTION

A plug-in hybrid electric vehicle (PHEV) is a type of hybrid electric vehicle that can use both grid electricity stored in batteries, and a liquid fuel as sources of energy. The use of grid electricity as an energy source reduces the use of conventional fuel and allows a PHEV to achieve reductions in greenhouse gas emissions, criteria emissions, and fueling costs [1]. Electrical energy is stored on-board a PHEV electrochemically in batteries, which are only able to store enough energy to drive the vehicle for a limited range. This means that a PHEV will generally operate in two modes: a charge depleting (CD) mode, in which the energy stored in the batteries will contribute to powering the vehicle, and a charge sustaining (CS) mode, in which conventional fuel provides all

of the required driving energy and the net change in battery energy is zero. PHEVs that drive farther than their CD range use both CD and CS modes of driving.

Because CD mode and CS mode are fundamentally different in terms of their energy sources, it is necessary to quantify and communicate the effect of each the two modes on metrics of vehicle fueling cost, emissions, and petroleum use. To this end, the SAE J2841 standard defines the concept of utility factor (UF), a method of weighting vehicle energy consumption in both CD and CS modes. SAE J2841 uses the National Household Transportation Survey (NHTS) as a model of consumer driving to provide a real-world basis for weighting

between a vehicle's CD and CS performance. In this way, the UF allows for a PHEV's energy consumption to be modeled in a way that is representative of real-world driving [2].

The J2841 UF is a tool that is widely used in policy and academic research. However, it contains several simplifying assumptions about consumers' use of PHEVs. These include an assumption that drivers will charge their battery only once per day and start the day with a fully charged battery, an assumption that the NHTS driving patterns are representative of PHEV driving patterns, and an assumption that a PHEV's CD range can be represented as a constant value. It has been previously shown that UF calculations are sensitive to variations in driver habits and vehicle characteristics [3, 4], but in the absence of real-world vehicle data, it has been difficult to evaluate the representativeness of the J2841 utility factors.

The EV Project is a large-scale plug-in electric vehicle and charging infrastructure demonstration, in which data is collected from consumer-owned Chevrolet Volt extended range electric vehicles. The Volt is an all-electric capable PHEV, where driving done in CD mode is done solely in electric vehicle (EV) mode. Once the Volt's high voltage battery is depleted, the vehicle operates in extended range mode using a CS control strategy.

The objective of this paper is to make a quantitative comparison between the J2841 UF and the UF as observed in the Chevrolet Volts enrolled in the EV Project.

DESCRIPTION OF THE EV PROJECT DATA SET AND METHODS

The data set analyzed in this paper comes from 1,405 privately owned Volts based in 18 metropolitan areas across the United States. Owners of these Volts were PHEV early adopters who chose to participate in The EV Project and consented to allow their vehicle usage to be monitored by OnStar as a term of their participation. Data parameters were collected from their vehicles wirelessly via OnStar, such as total distance driven, distance driven in EV mode, and battery state of charge. These parameters were logged each time the vehicle was turned on and off. Data analyzed in this paper were collected from October 2012 through June 2013 and include over 9 million miles (14.5 million km) of driving.

Vehicles were split into two groups by model year, because the 2013 model year (MY) Volt has a higher CD range than previous model years. Table 1 describes the characteristics of the data set used in this study.

Many of the MY2013 vehicles were enrolled in The EV Project after the start of the study period, which explains why this group produced fewer driving days and driving and charging events.

Table 1. Description of EV Project Volt data set being studied

MY	Number (%) of vehicles	Number (%) of vehicle driving days	Total distance driven – mi [km] (%)	Number (%) of charging events
2011/2012	787 (56%)	160,035 (70%)	6,477,419 [10,424,415] (70%)	232,120 (70%)
2013	618 (44%)	68,709 (30%)	2,827,140 [4,549,849] (30%)	98,199 (30%)
Total	1,405	228,744	9,304,559 [14,974,265]	330,319

COMPARISON OF OBSERVED AND CALCULATED FLEET UTILITY FACTORS

EV Project Fleet Observed Utility Factor

The observed utility factor of a vehicle fleet is simply calculated as the ratio of the distance driven by all vehicles in CD mode to the total distance driven by all vehicles. The observed utility factor of the two groups of Volts in the EV Project Volt data set is calculated in Table 2. EV Project Chevrolet Volts operated in EV mode for nearly three quarters of their driving distance.

Table 2. Observed utility factor of Volt groups

MY	Total distance driven – mi [km]	Distance driven in EV mode – mi [km]	Percent of distance driven in EV mode
2011/2012	6,477,419 [10,424,415]	4,689,022 [7,546,264]	72.4%
2013	2,827,140 [4,549,849]	2,088,496 [3,361,115]	73.9%

This observed utility factor can be compared to the estimated utility factor as calculated per J2841.

J2841 Fleet Utility Factor

The J2841 Fleet Utility Factor (FUF) is defined as the statistical probability that an average vehicle in the US will be driven less than or equal to a certain CD range (R_{CD}) on a particular day. For a given fleet of vehicles, the equation for the FUF is defined as follows:

$$FUF(R_{CD}) = \frac{\sum_{k=1}^N \min(d(k), R_{CD})}{\sum_{k=1}^N d(k)} \quad (1)$$

where k represents a single vehicle driving day, $d(k)$ is the distance that vehicle traveled in that day, and N is the total number of vehicle driving days in the data set. The J2841 FUF