

Seasonality Effect on Electric Vehicle Miles Traveled in Electrified Vehicles

N. Khalid Ahmed and Jimmy Kapadia
Ford Motor Company

ABSTRACT

The efficiency of an electrified powertrain is sensitive to fluctuations in temperature. This impacts the Electric Vehicle Miles Traveled (eVMT), or the miles travelled by Plug-In Hybrid Electric Vehicles (PHEVs) using electrical grid power. In this paper, we discuss various methods used to calculate eVMT for PHEVs and propose an alternate method to calculate eVMT with higher accuracy using real world customer data. Real world customer data is obtained through telematics modems on Ford Energi products powered by the “MyFord Mobile” web and phone applications. Customer and season specific data from pure charge depleting and pure charge sustaining trips are used in this method to generate a customer and season specific conversion factor. As a result, this real world data based method helps track the effect of seasonality on eVMT obtained by customers in a combination of all charge depleting and charge sustaining trips.

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INTRODUCTION

Electrified powertrain vehicles have an electrical energy input and path to the wheels, either in place of or in addition to, the gasoline fuel energy and mechanical path in conventional internal combustion engines [1]. These vehicles include (a) pure electric vehicles known as Battery Electric Vehicles (BEVs) – for e.g. Ford Focus Electric, Nissan Leaf etc.; (b) a combination of electrical and mechanical powertrains known as Fully Hybrid Electric Vehicles (FHEVs) – for e.g. Ford Fusion Hybrid, Ford C-Max Hybrid, Toyota Prius etc.; and (c) a combination of BEVs and FHEVs known as Plug-In Hybrid Electric Vehicles (PHEVs) – for e.g. Ford Fusion Energi, Ford C-Max Energi, Chevy Volt etc. The specific powertrain architecture of these electrified vehicle types can be different from each other. Despite these differences, it is well known that different seasons throughout a year have different effects on all electrified vehicles [2, 3]. In this work, we develop a novel method to quantify the effect of seasonality on the capability of PHEVs and show results that match expectations on the impact of seasons on these vehicles. We also like to point out that the electric operation in electrified vehicles depends on terrain, driving behavior, battery size, and other factors. By studying Ford Energi vehicles, we have limited ourselves to a single point on vehicle parameters like battery size, making them a control variable in this work. The large number of customers in this study averages out other factors such as terrain and vehicle driving behavior.

Electric Vehicle Miles Traveled (eVMT)

We evaluate the effect of seasons on PHEVs by a parameter proposed by the California Air Resources Board (ARB): the Electric Vehicle Miles Traveled (eVMT) [4, 5]. Electric Vehicles Miles Traveled are defined as the number of miles that a customer drives in a pure

electric manner using electrical energy obtained through a wall port that is transferred to the wheels through an electrical path. This typically involves the storage of electrical energy in a battery and the use of this energy through a motor connected to the wheels. In the case of BEVs, where this is the only possible powertrain architecture, all customer miles are eVMT miles. However, in the case of PHEVs, when the available electrical energy in the battery is depleted, the conventional internal combustion engine continues to drive the vehicle. In this case, the customer miles accrued before the conventional internal combustion engine takes over are eVMT miles while those accrued after the event are not eVMT miles. In addition to depletion of electrical energy, the internal combustion engine in a PHEV can also be activated in response to customer demands such as high power requests and extreme climate control requirements. In these cases, the eVMT miles are further decreased and appropriate modifications to calculation methods need to be implemented to include these factors.

MyFordMobile Connectivity (MFM)



Figure 1. Implementation of MyFord Mobile connectivity. This figure shows a customer communicating to his electrified vehicle, a Ford Focus Electric, through cellular technology. The customer connects to a Ford cloud-based secure server which in-turn communicates with his vehicle [6].

MyFord Mobile is a smartphone app, website and connectivity feature [6] that enhances the electrified vehicle ownership experience for Ford customers. MyFord Mobile uses an onboard wireless module integrated into the vehicle allowing the car to communicate with the Ford cloud-computing service through familiar cellular technology, as shown in Figure 1. MyFord Mobile allows customers to communicate with the Ford cloud-based secure server to view and monitor their vehicle's battery state of charge, get updated charge station information and remotely access their car from anywhere at any time.

Using this technology, trip summary statistics of every trip taken by every customer are also uploaded to the Ford cloud-based secure servers. As shown in figure 2, these statistics include the total trip distance, electric energy used, gasoline fuel used, trip distance driven with the engine off among other parameters. These statistics are received at the end of each trip, providing data from trips that include different geographical locations, different temperatures and seasons, and different customer driving habits [7].

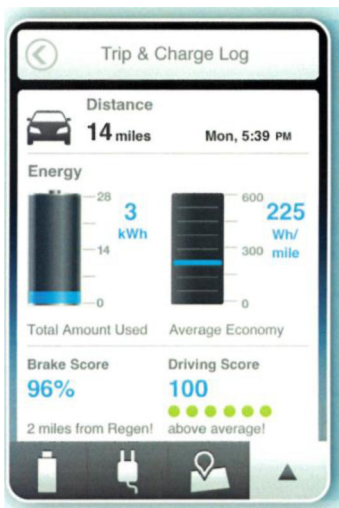


Figure 2. Trip summary statistics. This figure shows a sample of trip summary statistics that are immediately available at the end of each trip. These statistics are uploaded to Ford cloud-based secure servers, allowing for real-world analytics to be performed on electrified vehicles [6].

Customer privacy is of utmost importance throughout the MyFord Mobile project and in our work. In this paper, analysis is performed with only non-personally identifiable data on vehicle performance. Additionally, this analysis is performed on an aggregate level and does not identify any customer or his vehicle individually. We compile aggregate and statistical data and present general trends in vehicle behavior in this work. We eventually hope to use this aggregate data about our vehicles to develop new and improved products and services.

METHOD

The Electric Vehicle Miles Traveled (eVMT) is a metric that is calculated for each trip [8]. In the case of BEVs, i.e. all electric trips, the eVMT is equivalent to the trip distance. In the case of FHEVs, where there is no means to input electrical energy from the grid into

the vehicle, the eVMT is zero. In the case of PHEVs, which can be considered to be a combination of BEVs and FHEVs, a certain fraction of the trip distance is the eVMT fraction.

A vehicle average method used to calculate the eVMT fraction per trip on a PHEV was previously proposed by the Idaho National Lab. This method calculates an average electric energy to miles traveled conversion and an average fuel gallons to miles traveled conversion for each vehicle. We describe this method in the following sub-section. In comparison to this INL method, our approach proposes calculating an average conversion factor which is cognizant of the effect of seasons by considering a moving average of every vehicle for every month in a year. We describe our method in detail in the next sub-section.

The trips on a PHEV are categorized into

- pure charge deplete trips (CD),
- pure charge sustain trips (CS), and
- blended trips.

In pure charge deplete trips (CD), only electric energy is used to power the entire trip – as a result, these trips are less than the all-electric range of the PHEV. The entire trip distance on these trips is equal to the eVMT distance. These trips are represented by point A in Fig. 3, where vehicle conversion efficiency can be calculated for electric energy to miles in units of Watt-hr per mile.

In pure charge sustain trips (CS), only gasoline fuel is used to power the entire trip – as a result, these trips typically begin with a zero percent customer state of charge in their high voltage battery. No part of the trip distance on these trips is equal to the eVMT distance. These trips are represented by point C in Fig. 3, where vehicle fuel consumption can be calculated for gallons to miles in units of Gallons per mile.

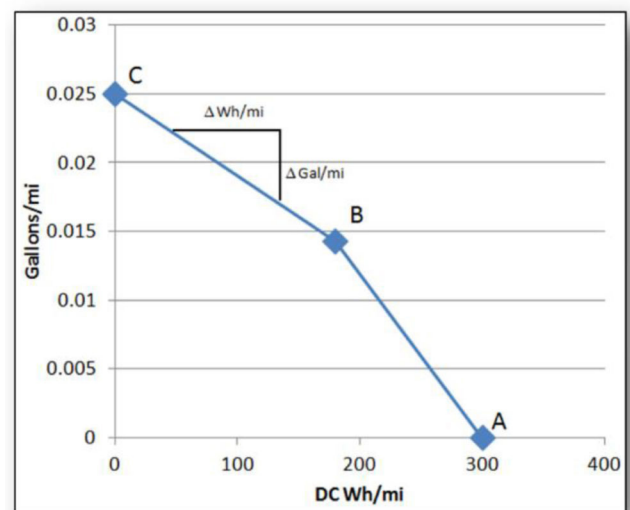


Figure 3. Distribution of energy sources on PHEV Trips. A) In a charge deplete trip (CD), as shown by point A above, the only source of energy is electricity – labelled as Direct Current Watt-hours per mile. B) In blended trips, as shown by point B above, there is a combination of energy from electricity and gasoline. C) In a charge sustain trip (CS), as shown by point C above, the only source of energy is gasoline fuel. Figure reproduced from Idaho National Lab's report available on their website [4].

In blended trips, represented by point B in Fig. 3, both electric energy and gasoline fuel is used to power the trip. In these trips, a certain fraction of the trip's distance is attributed to electric energy while the remainder is attributed to gasoline fuel. In the following sub-sections we describe how this fraction was previously calculated by the Idaho National Labs, and our proposed improvement to their method.

Vehicle Average Method

This method was originally developed at the Idaho National Lab [4, 8]. In this method, a metric called the Gallons Displaced is calculated per trip. This is equivalent to the gallons of gasoline that would have been used per trip which was avoided by the usage of electric energy. The Gallons Displaced is calculated per trip using the equation:

$$\text{Gallons Displaced per trip} = \text{kWhr consumed per trip} \times \frac{\Delta \text{gal}/\text{mi}}{\Delta \text{kWhr}/\text{mi}} \quad (1)$$

where, kWhr consumed per trip is the electric energy consumed in a blended trip, and $\Delta \text{gal}/\text{mi}$ and $\Delta \text{kWhr}/\text{mi}$ are vehicle average numbers for average energy consumption in charge deplete (CD) and charge sustain (CS) modes respectively [9, 10]. This method is shown in Fig. 3. By calculating the vehicle average $\Delta \text{gal}/\text{mi}$ and $\Delta \text{kWhr}/\text{mi}$, the points A and C shown in Fig. 3 are determined. Next any blended trip, represented by point B, can be proportionally divided between points A and C by calculating the corresponding Gallons Displaced for the trip represented by point B.

Using the calculated Gallons Displaced per trip, the eVMT distance per trip is calculated using the equation:

$$\text{eVMT} = \text{Trip Distance} \times \frac{\text{Gallons Displaced}}{\text{Gallons Displaced} + \text{Gallons Consumed}} \quad (2)$$

where, gallons displaced is calculated from Eq. 1, and gallons consumed is the gallons of gasoline consumed per trip.

In this method, the vehicle averaged inputs do not consider any seasonality effects on them. Thus the eVMT distance calculated is not sensitive to the effect of ambient temperature on the electrified powertrain.

Seasonality Cognizant Method

In our method, we consider individual trip data collected through MyFord Mobile. As a first step, we group all trips based on customers, and every monthly period of their usage across the years. This process allows us to calculate individualized metrics per month that are used in our seasonality cognizant method. As shown in Fig. 4, in comparison to the vehicle average method of figure 3 [4], we have individual points of A and C that represent different months of the year. By using different points A1 – A12 and C1 – C12, we are now able to calculate different Charge Deplete (CD) vehicle conversion efficiencies and different Charge Sustain (CS) vehicle fuel consumption efficiencies according to both the individual customer and the different months of a year.

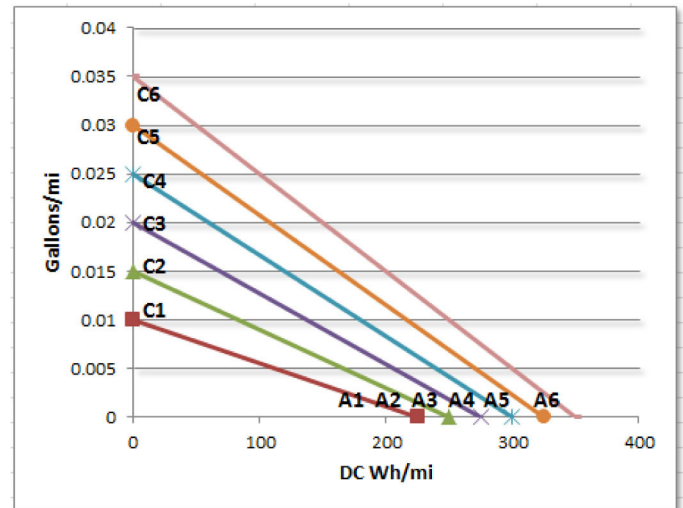


Figure 4. Distribution of energy sources on PHEV Trips using the seasonality cognizant method. The energy from Charge Deplete (CD) trips are represented by all points marked A, where the following number is representative of different months in a year. Similarly, Charge Sustain (CS) trips are represented by all points marked C, where the following number is representative of different months in a year. Numbers on this plot are for illustrative purposes only.

$$\text{EV Efficiency} = \frac{\text{Electric Energy Used in pure CD Trip}}{\text{Total Miles Traveled}} \quad (3)$$

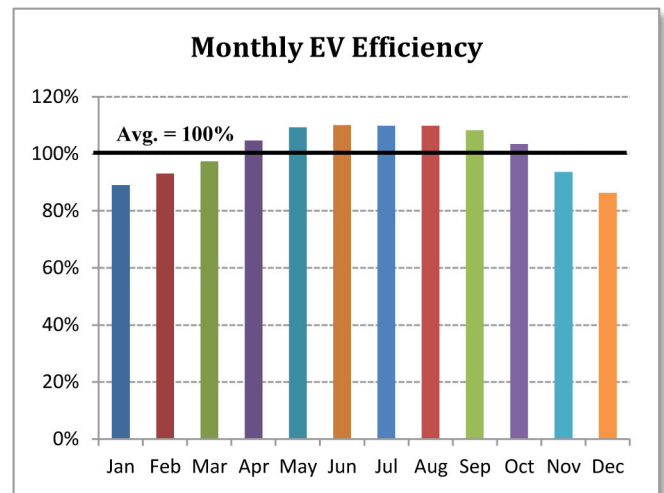


Figure 5. Different months of the year have different EV efficiencies due to the effect of seasons on electrified powertrains. In order to account for this effect, we present a new seasonality cognizant method to calculate eVMT distances in blended trips where both gasoline fuel and electric energy are used.

We consider pure charge deplete trips (CD) and calculate the EV Efficiency by considering the energy used for miles traveled as shown in Eqn. 3. This average vehicle conversion EV efficiency is calculated per customer, per month, per year from pure CD trip. This reflects the on-road real world efficiency obtained by each customer and is cognizant of each customer's driving habits [11], road loads faced by individual customers, and weather effects on customer experience. These are important parameters that are known to affect