

	SURFACE VEHICLE INFORMATION REPORT	
	SAE	J2841 SEP2010
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(R) Utility Factor Definitions for Plug-In Hybrid Electric Vehicles Using Travel Survey Data		

RATIONALE

Describing the fuel and electrical energy usage of plug-in hybrid electric vehicles (PHEVs) is very challenging for the reason that these values vary greatly depending upon the distance traveled between charging. Detailed test procedures recommended for PHEVs are found within SAE J1711, this document serves to supply appropriate UF curves for the equations in that document that weigh the charge depleting mode operation with the charge-sustaining operation depending upon the charge-depleting mode distance measured from the test. The original issue of SAE J2841 introduced the Utility Factor based upon a mileage-based "Fleet" analysis of the US DOT National Household Transportation Survey data. This issue of SAE J2841 adds more options to the Utility Factor calculations by analyzing another data set from a Georgia Tech called the "Commute Atlanta" in order to find a vehicle-weighted analysis.

1. SCOPE

This SAE Information Report establishes a set of "Utility Factor" (UF) curves and the method for generating these curves. The UF is used when combining test results from battery charge-depleting and charge-sustaining modes of a Plug-in Hybrid Electric Vehicle (PHEV). Although any transportation survey data set can be used, this document will define the included UF curves by using the 2001 United States Department of Transportation (DOT) "National Household Travel Survey" and a supplementary dataset.

1.1 Purpose

In use, the fuel and energy consumption rates of a PHEV vary depending upon the distance driven between charge events. For PHEVs, the baseline assumption regarding any UF is that operation starts fully charged and begins in charge-depleting mode. Eventually, the vehicle must change to a charge-sustaining mode. The vehicle miles traveled between charge events determines how much of the driving is performed in each of the two fundamental modes. A second assumption is that charging occurs every day after the day's driving is complete, i.e. once per day. In the absence of PHEV driver behavior data, the two additional unknown driver behavior issues of (1) how often charging occurs during the day ("opportunity charging") and (2) how often a driver will forget to charge, are assumed to be equally offsetting, thus the baseline assumes one charge per day of operation.

Given the previous assumptions, a UF describes the fraction of driving in each of the fundamental modes using a given set of recorded in-use driving data. Driving statistics from the 2001 National Household Travel Survey and a supplementary dataset are used as inputs to the UF creation to provide UF curves applicable to a vehicle's charge-depleting mode results.

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2. REFERENCES

2.1 Applicable Documents

SAE 810265, Burke, A.F. and Smith, G.E., "Impacts of Use-Pattern on the Design of Electric and Hybrid Vehicles"

SAE J1711, "Recommended Practice for Measuring the Exhaust Emissions and Fuel Economy of Hybrid-Electric Vehicles, Including Plug-in Hybrid Vehicles"

SAE J1715, "Hybrid Electric Vehicle (HEV) & Electric Vehicle (EV) Terminology"

2001 National Household Travel Survey (NHTS), U.S. Department of Transportation, website:
http://www.bts.gov/programs/national_household_travel_survey/

Commute Atlanta Study Overview, Georgia Tech. School of Civil and Environmental Engineering, website:
<http://commuteatlanta.ce.gatech.edu/>

Federal Register, Vol. 71 No. 248, Page 77904, December 27, 2006

3. DEFINITIONS

3.1 HYBRID ELECTRIC VEHICLE (HEV)

A road vehicle that can draw propulsion energy from both of the following sources of stored energy: (1) a consumable fuel and (2) a rechargeable energy storage system (RESS) that is recharged by an electric motor-generator system, an external electric energy source, or both.

3.2 PLUG-IN HYBRID-ELECTRIC VEHICLE (PHEV)

A classification describing an HEV with an energy storage system that is designed to be recharged from an external (off-vehicle) electric energy source, typically an AC electrical power supply system.

NOTE: Equivalent to "Off-Vehicle Charge Capable HEV," "Grid-Connected HEV," and "Externally Chargeable HEV"

3.3 VEHICLE MILES TRAVELED (VMT)

Vehicle Miles Traveled (VMT) is the total distance traveled by a vehicle in units of miles.

3.4 UTILITY FACTOR (UF)

The UF indicates the limited utility of a particular initial operating mode - for PHEVs, the CD mode. An operating mode with a very long range, for example, will have a very high utility and, thus, a UF that approaches 1.0. The UF is a function of a vehicle's charge depleting range. The UF is defined by using the assumptions that (1) the vehicle starts the day from a routinely achieved, fully charged state and (2) the vehicle is charged to said state before every day of vehicle travel. As will be discussed later in the document, many possible utility factors can be created and care must be exercised when deciding which utility factor to use for a particular analysis.

3.5 FLEET UTILITY FACTOR (FUF)

The FUF is a utility factor based on the total miles traveled for a specific fleet of vehicles. This UF is created by dividing the depleting miles by the total miles traveled. This UF is particularly useful to calculate the expected fuel and electric energy consumption of an entire fleet of vehicles. The FUF evaluated between 0 and 400 miles is shown in Appendix B.

3.6 INDIVIDUAL UTILITY FACTOR (IUF)

An IUF (IUF) considers all vehicles equally as opposed to using daily VMT weighting which is highly weighted towards long distance trips. This particular utility factor is analogous to the average individual response to a survey of fuel and electric energy consumption rates for a set of vehicles. Two possible options for an IUF are the Single Day and Multiple Day IUFs, which are differentiated by the availability of multiple survey days in the data.

3.7 SINGLE DAY INDIVIDUAL UTILITY FACTOR (SDIUF)

The SDIUF is a specific IUF created when only a single day of travel is available. For most analysis, data from a multi-day survey is more representative for generating IUFs. This is due to the variations of a driver's behavior not being adequately captured using a single day travel survey.

NOTE: The 2001 NHTS survey data only includes data from a single day per household.

3.8 MULTIPLE DAY INDIVIDUAL UTILITY FACTOR (MDIUF)

The MDIUF is a specific IUF created when multiple driving days are available from a travel survey dataset. The MDIUF better incorporates a driver's day-to-day variation into the utility calculation. This is the recommended utility factor to use when calculating an IUF to estimate an individual vehicle's expected fuel economy. The MDIUF evaluated between 0 and 400 miles is shown in Appendix B.

3.9 SPECIFIC UTILITY FACTOR (SUF)

A Specific Utility Factor is a utility factor that uses a filtered subset of data to create a utility factor that represents a certain driving style. The reasoning behind this type of UF is that certain driving styles may have different distance distributions for daily miles traveled and thus may be analyzed with different UFs. For example, if one assumes that a certain driving style leads to shorter daily distances, it might be useful to use a shorter distance subset of a travel survey to create a UF curve for that driving style. Cycle-specific utility factors can be created for either FUFs or IUFs. Note: the applicability of a particular SUF is directly related to the ability to confidently separate driving styles given the amount of information in a particular dataset.

3.10 CITY SPECIFIC FLEET UTILITY FACTOR (CSFUF)

The CSFUF is a Specific Fleet Utility Factor created for City (Urban) driving. Two examples of a CSFUF curve can be found in Appendix E.

3.11 HIGHWAY SPECIFIC FLEET UTILITY FACTOR (HSFUF)

The HSFUF is a Specific Fleet Utility Factor created for Highway driving. Two examples of a HSFUF curve can be found in Appendix E.

3.12 CHARGE-DEPLETING (CD) MODE

Operating mode of a HEV in which the vehicles run by consuming only the electric energy from the mains or along with the fuel energy simultaneously or sequentially until the CS Mode state.

3.13 CHARGE-SUSTAINING (CS) MODE

Operating mode where the HEV runs by consuming the fuel energy while sustaining the electric energy of the RESS.

3.14 CHARGE-DEPLETING RANGE (R_{CD})

Generally speaking, this is the distance a vehicle can travel in Charge-Depleting Mode. Several different range calculations are possible and are specified in SAE J1711.

4. DERIVATION OF UTILITY FACTORS

4.1 Illustrating the Utility Factor Concept

The derivation of a UF requires a data set of daily driving distances by a number of drivers. The following example will illustrate the derivation. Let there be a driving data set of five (5) vehicles that all have different daily miles traveled. Let the charge-depleting range be 40 miles in this example. For this CD range, each vehicle has a different percentage of operation in CD mode. If the miles traveled were less than or equal to 40 miles, then 100% of the driving is in CD mode. If a driver's miles traveled are higher than the CD range, then the CD range divided by the total miles defines this driver's fraction of CD mode travel. Figure 1 illustrates this example driving dataset.

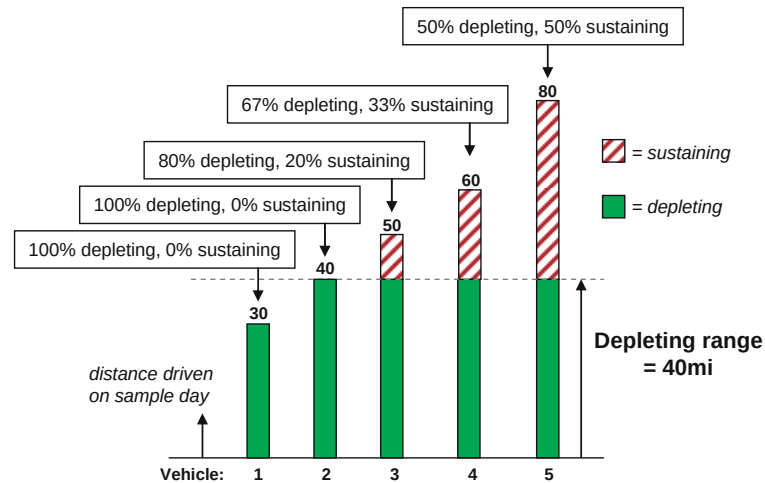


FIGURE 1 - SAMPLE ILLUSTRATION OF AN ORDERED SET OF DAILY DRIVING DISTANCES

To calculate a VMT-weighted UF for this fleet of vehicles, all of the depleting miles are divided by the total miles. In the numerator, the distance is either the driven distance or the CD range, whichever value is lowest, summed over all drivers. The denominator is the sum of the total miles driven by the fleet. For this example, the calculation is shown in Figure 2. Given the usefulness of this factor for describing the expected fuel consumption of an entire fleet of vehicles, it is referred to as the Fleet Utility Factor (FUF)

$$UF(40) = \frac{\text{Depleting Miles}}{\text{Total Miles}} = \frac{30 + 40 + 40 + 40 + 40}{30 + 40 + 50 + 60 + 80}$$

FIGURE 2 - FLEET UTILITY FACTOR CALCULATED FOR EXAMPLE ILLUSTRATION

As an alternative to the FUF, the Individual Utility Factor (IUF) considers all vehicles equally as opposed to using a VMT weighting which is highly weighted towards long distance trips. If one wanted to find an individual vehicle-weighted utility factor (IUF), as opposed to a VMT weighted utility factor, this would be found by summing the individual fractions of CD operation versus total miles driven for all drivers and then dividing by the total number of drivers. The fraction of CD operation is defined as 1.0 for drivers driving less than or equal to the CD range and the fraction of CD operation for drivers driving farther than the specified CD range is defined as the charge depleting range divided by the total distance traveled. This utility factor is described in Figure 3. Given the relevance of this utility factor for individual vehicles, this type of utility factor is commonly referred to as an Individual Utility Factor (IUF). In the case of the NHTS, where only one day of driving data is available, this type of utility factor would be termed a Single Day Individual Utility Factor (SDIUF).

$$UF(40) = \frac{1}{5} (1 + 1 + 0.8 + 0.67 + 0.5)$$

Depleting Fractions
Number of Vehicles

FIGURE 3 - INDIVIDUAL UTILITY FACTOR CALCULATED FOR EXAMPLE ILLUSTRATION

Which factor to use for analysis of a particular PHEV depends upon the purpose of the analysis. If the intent is to predict the combined fuel usage of a fleet of vehicles, then the mileage-weighted Fleet UF concept (FUF) should be used. If the intent is to find a prediction of an individual vehicle's expected fuel economy, then a vehicle-weighted Individual Utility Factor (IUF) result should be used.

While the expected fuel consumption of a collection of drivers on a single day can be calculated from the NHTS data, it is also useful to observe daily driving distance over a period of time. This is because drivers will typically have a varying driving distance profile over the course of the year due to business trips, vacations, etc. Since this data is not directly available from the NHTS data, an additional data set was used to incorporate longer term driving behavior. The supplementary dataset used for this analysis was from a Commute Atlanta (CA) survey of roughly 530 vehicles. Although this dataset is much smaller, it contains multiple days of driving data and therefore provides insight into longer term driving patterns that the NHTS data alone is unable to address. With this supplementary dataset, a new Multi-day Individual Utility Factor (MDIUF) may be calculated in a similar fashion to the SDIUF with the inclusion of the multiple driving days. When using an individual utility factor, it is recommended that a MDIUF be used.

4.2 Defining Utility Factor Equations

Let S be a reference set of driving data, which is a finite set of driving distances, and let R_{CD} be a given CD range. Let d_i be a daily distance driven by a particular vehicle. Let N_s be the total number of vehicles multiplied by the total number of driving days considered in the set S . Equation 1 illustrates the membership in this set.

$$S = \{d_1, d_2, \dots, d_{N_s}\} \quad (\text{Eq. 1})$$

When S is ordered such that $(d_i \leq d_{i+1})$, the sorted daily driving distances can be plotted, as shown in Figure 4.

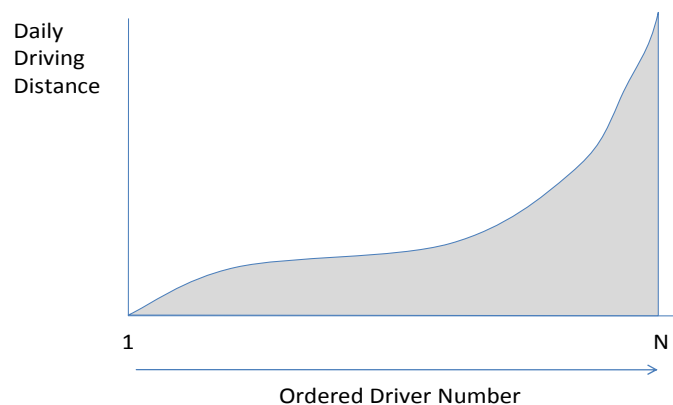


FIGURE 4 - ORDERED REFERENCE SET OF N DAILY DRIVING DISTANCES

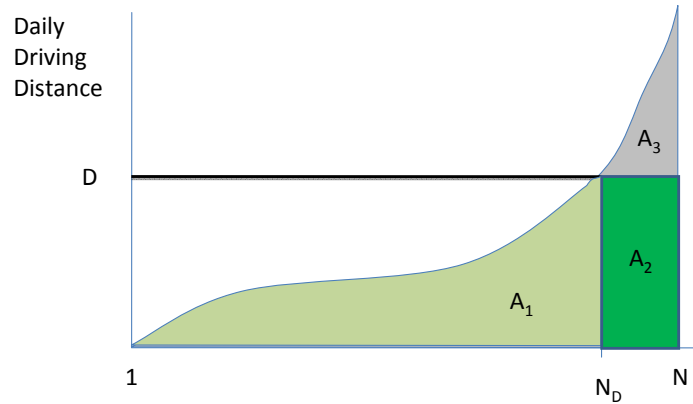


FIGURE 5 - DATA PARTITIONS FOR UTILITY FACTOR (UF) DERIVATION

Consider the partitions illustrated in Figure 5 for the following parameters. The fraction of drivers traveling less than D miles per day is described in Equation 2.

$$F(D) = \frac{N_D}{N} \quad (\text{Eq. 2})$$

The fraction of VMT driven in the initial mode up to D miles (charge-depleting or EV range, D) is depicted in Equation 3.

$$UF(D) = \frac{A_1 + A_2}{A_1 + A_2 + A_3} \quad (\text{Eq. 3})$$

Thus, the UF calculation, given the initial data set S , is the sum of the minimum of either R_{CD} or the driving distance of d_k data, divided by the sum of all the distances. This calculation is shown in Equation 4.

$$UF(R_{CD}) = \frac{\sum_{d_k \in S} \min(d_k, R_{CD})}{\sum_{d_k \in S} d_k} \quad (\text{Eq. 4})$$

As discussed previously, an IUF may be desirable when conveying information for an average vehicle. The basic buildup of this utility factor is similar to the previous discussion, but rather than a percentage of total miles traveled, this utility factor represents the expected depleting fraction enabled by a particular depleting range relative to the set of vehicles. Equation 5 illustrates this calculation.

$$IUF(R_{CD}) = \frac{\sum_{i=1}^{nVehicles} \frac{\sum_{j=1}^{nDays} \min(d_{i,j}, R_{CD})}{\sum_{j=1}^{nDays} d_{i,j}}}{nVehicles} \quad (\text{Eq. 5})$$

5. NHTS AND COMMUTE ATLANTA SURVEY BACKGROUND

"The National Household Travel Survey (NHTS) is a U.S. Department of Transportation (DOT) effort sponsored by the Bureau of Transportation Statistics (BTS) and the Federal Highway Administration (FHWA) to collect data on both long-distance and local travel by the American public. The joint survey gathers trip-related data such as mode of transportation, duration, distance and purpose of trip. It also gathers demographic, geographic, and economic data for analysis purposes." - Obtained February 2010 from http://www.bts.gov/programs/national_household_travel_survey/

The 2001 NHTS was conducted during the period March 2001 through May 2002. Each sampled household was assigned a travel day to report all trips made on that day. Travel days were assigned for all seven days of the week, including holidays. The travel day began at 4 AM and ended at 3:59 AM of the following day. On a typical day, 4 AM represents the time when the fewest number of people are in the middle of a trip.

"In 2004, Commute Atlanta monitored one full year of baseline travel activity from more than 275 participating households. These volunteer households allowed the research team to professionally install a GT Trip Data Collector in their vehicles. Approximately 465 vehicles in these households were equipped with instrumentation to monitor second-by-second vehicle speed and position for every trip. Researchers remotely monitor the travel patterns of these vehicles, uploading vehicle and engine operating data via a cellular data connection. General travel data, such as number of trips per household per day and selected travel routes, are used to evaluate transportation demand models currently used in Atlanta's transportation planning process. Vehicle position and speed data are used to identify locations of recurrent traffic congestion..."

"More than 100 households participated in Phase II value-pricing research designed to assess household travel response to simulated payment of transportation costs on a per-mile basis. A similar number of households will experience real-time congestion pricing later this year. Analytical efforts for this project are expected to continue throughout 2007." - Obtained February 2010 from <http://commuteatlanta.ce.gatech.edu/>

By filtering the Commute Atlanta dataset, the multi-day driving patterns of the survey drivers may be calculated and used as a multi-day supplement to the NHTS data.

The CA dataset was found to have FUF and SDIUF distributions similar to the NHTS dataset and was therefore decided to be a reasonable supplement to the NHTS dataset. The following Figures 6 and 7 compare the Commute Atlanta and NHTS data sets relative to the FUF and SDIUF curves. The plots on the right side of Figures 6 and 7 are an expanded view of the curve between 0 and 100 miles.

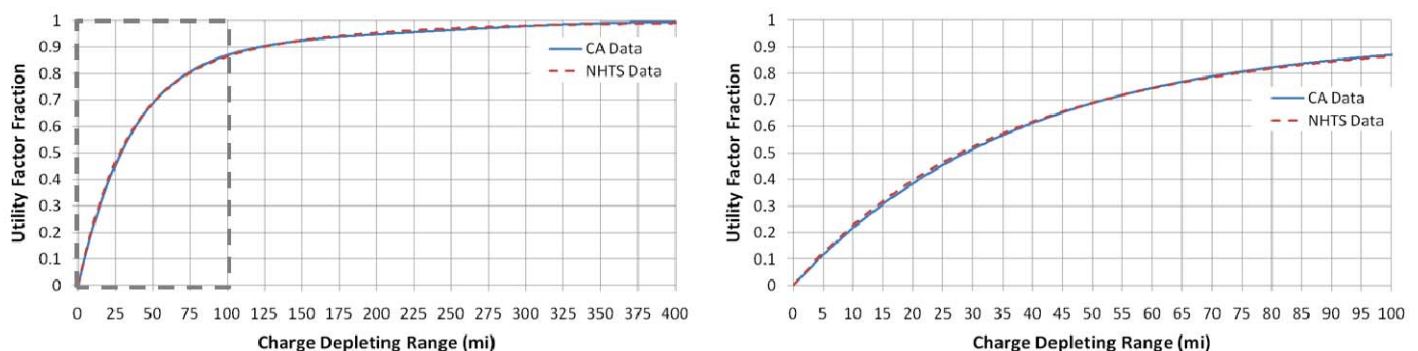


FIGURE 6: FLEET UTILITY FACTOR COMPARISON: COMMUTE ATLANTA (CA) VERSUS NHTS (FULL AND <100 MI)

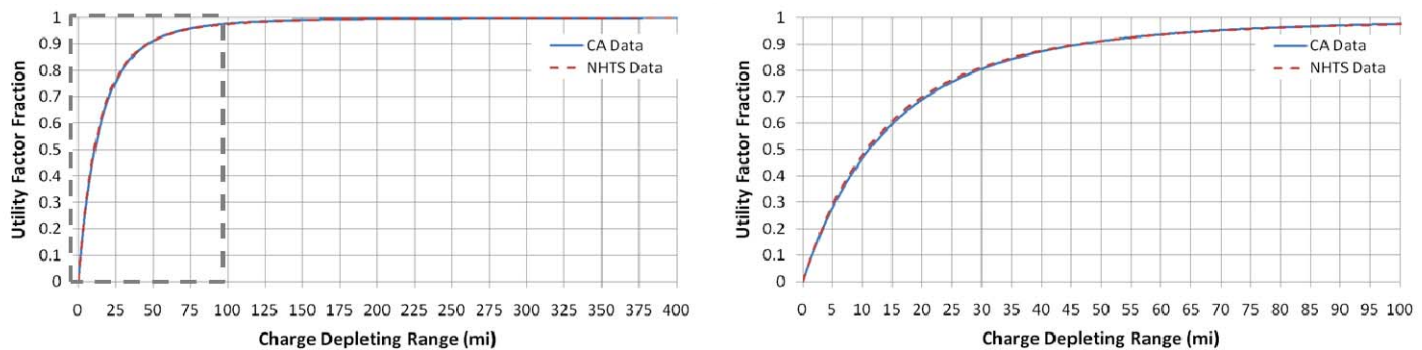


FIGURE 7 - SINGLE-DAY INDIVIDUAL UTILITY FACTOR COMPARISON: COMMUTE ATLANTA (CA) VERSUS NHTS (FULL AND <100 MI)

6. UTILITY FACTOR PROCESSING AND VALUES

6.1 Data Processing

The 2001 NHTS data in the “Day Trip File” named DAYPUB comes in SAS, database, and ASCII format. It consists of separate individual trips from the entire survey. The total number of records in the file is 642 292. The data were reduced by using the filters and selected parameters listed in Table 1.

TABLE 1 - FIELDS USED TO EXTRACT SET OF DAILY DRIVING DISTANCES FROM NHTS DATA

Field	Filter	Remarks
DRVR_FLG	=1	1 = Subject was driver on this trip
SMPLSRCE	=1	1 = National Sample
TRPMILES	>0	Trip distance in miles
TRVL_MIN	>0	Time to complete entire trip in minutes
VEHTYPE	= 1, 2, 3, or 4	Type of vehicle, 01=Car, 02=Van, 03=SUV, 04=Pickup truck, 05=Other truck, 06=RV, 07=Motorcycle, 91=Other

One last step was taken before the UF equations could be applied. For each household vehicle (unique “HOUSEID” and “VEHUSED” label in data set) that was used on the travel day, trip distance and trip time were summed to arrive at daily vehicle usage. The resulting data provides daily driving distances for roughly 32 000 vehicles and is used alongside the supplementary dataset as the input for the utility factor analysis in this document.

6.2 Utility Factor Exponential Equation Fits

The various UF results can be described by entering the depleting range into the general form shown in Equation 6, where x is the input depleting range. The coefficients for the FUF and MDIUF fit calculations are shown in Table 2. The UF results are valid from 0 to the normalized distance where the Utility Factor converges to 1.0. The equation structure for fitting a UF curve was arrived at experimentally and was found to provide a good fit with relatively few coefficients or significant digits. The fit coefficients were found using a modified least squares approach, which ensures that the fits are monotonic. The fit coefficients for the FUF are identical to those found in the previous version of SAE J2841. For the MDIUF, the fitting algorithm was further adjusted to achieve a mix of low relative error and a minimum number of coefficients/significant digits. The maximum fit-error was less than 0.004 and 0.007 for the FUF and MDIUF respectively. An example fitting script is shown in Appendix A and may be adjusted to find the desired coefficient number and resolution to be used in Equation 6.

$$UF = 1 - \exp\{ -[C1*(x/norm_dist) + C2*(x/norm_dist)^2 + \dots + C10*(x/norm_dist)^{10}] \} \quad (\text{Eq. 6})$$

TABLE 2 - UTILITY FACTOR EQUATION COEFFICIENTS

Value	FUF Fit	MDIUF Fit
norm_dist	399.9	400
C1	10.52	1.31E+01
C2	-7.282	-1.87E+01
C3	-26.37	5.22E+00
C4	79.08	8.15E+00
C5	-77.36	3.53E+00
C6	26.07	-1.34E+00
C7	-	-4.01E+00
C8	-	-3.90E+00
C9	-	-1.15E+00
C10	-	3.88E+00
Max Error	0.00391	0.00658

Due to some unique processing requirements, the Multi-day Individual utility factor has a limited set of points available for data fitting. More specifically, the MDIUF data was fit using 20 points distributed across the entire 400 mile range. In order to provide a more accurate fit in the regions of typical interest, the majority of the fit points were allocated between 0 and 50 miles. To evaluate that this reduced set of points was sufficient to match UF shaped data, a fit was created using the full FUF curve and the 20 point reduced set. Figure 8 shows that the reduced point fit is close to the full-data fit and suggests that the 20 points used for fitting the MDIUF should be suitable.

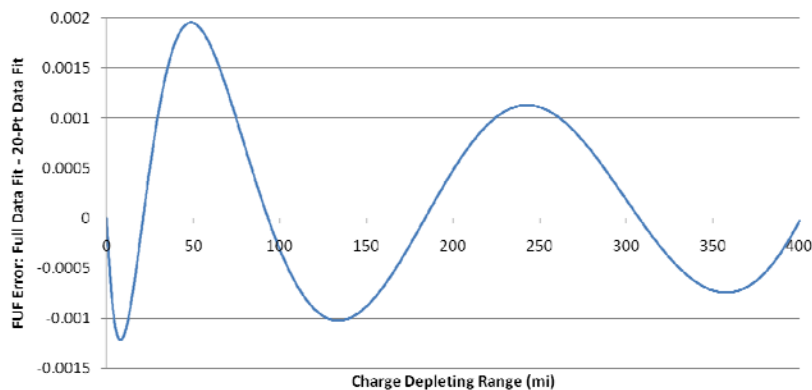


FIGURE 8 - FULL AND 20 POINT FUF CURVE ERROR PLOT

Utilizing Equation 6 and the coefficients in Table 2, the Fleet Utility Factor and Multi-day Individual Utility Factor curves are shown in Figure 9. The plot on the right side of Figure 9 shows an expanded view of the Utility Curves in the 0 to 100 mile range. Appendix B contains a table of the FUF and MDIUF equations evaluated at 1 mile increments and rounded to the nearest 0.001. For non-integer distances, it is recommended that the proper UF fit equation be evaluated to calculate the UF.

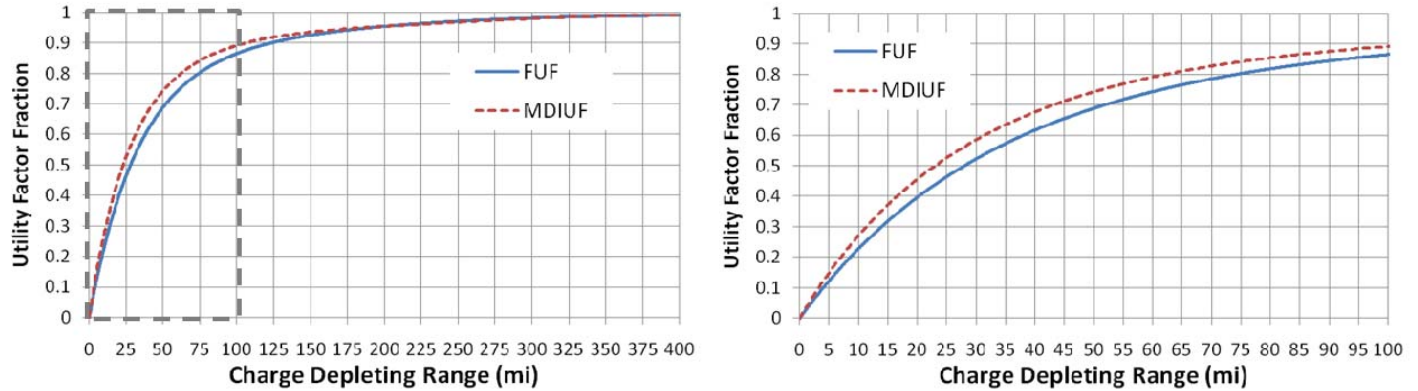


FIGURE 9 - FUF AND MDIUF WITH RESPECT TO CHARGE-DEPLETING RANGE

7. CITY AND HIGHWAY SPECIFIC UTILITY FACTORS

7.1 Calculating City and Highway Specific Utility Factors

In the FUF and MDIUF, all driving data from a particular survey is included together to create the UF curve. However, different types of driving may differ in the distribution of distance traveled. For example, some high-speed drivers will likely travel farther than the majority of stop-and-go drivers. Because energy consumption for a PHEV is a function of distance driven between charges, a UF which is specific to either a particular style of driving may be useful. A UF constructed for use with a particular type of driving is referred to as a Specific Utility Factor (SUF) and can be created as either an FUF or IUF.

The City and Highway Specific UFs can be built from a data set that contains the distance driven between charges for one or more vehicles over one or more days. For simplicity, one charge per day is assumed. The equations are normalized to work with data sets of one or more days of data per vehicle. Each data point in the set is assigned a weight with a value between zero and one. Using this data, the cycle-specific FUF for a fleet is shown in Equation 7. More information regarding the properties of Specific UFs can be found in Appendix D.

$$SUF_{Fleet}(R_{cd}) = \frac{\sum_{k=1}^K \frac{1}{N_k} \cdot \sum_{n=1}^{N_k} w_{k,n} \cdot \min(R_{cd}, d_{k,n})}{\sum_{k=1}^K \frac{1}{N_k} \cdot \sum_{n=1}^{N_k} w_{k,n} \cdot d_{k,n}}$$

(Eq. 7)

Similarly, the cycle-specific IUF for an individual is shown in Equation 8.

$$SUF_{Individual}(R_{CD}) = \frac{\sum_{k=1}^K \left(\left(\frac{\sum_{n=1}^{N_k} w_{k,n} \cdot d_{k,n}}{\sum_{n=1}^{N_k} d_{k,n}} \right) \cdot \left(\frac{\sum_{n=1}^{N_k} w_{k,n} \cdot \min(R_{CD}, d_{k,n})}{\sum_{n=1}^{N_k} w_{k,n} \cdot d_{k,n}} \right) \right)}{\sum_{k=1}^K \left(\frac{\sum_{n=1}^{N_k} w_{k,n} \cdot d_{k,n}}{\sum_{n=1}^{N_k} d_{k,n}} \right)}$$

(Eq. 8)

TABLE 3 - CYCLE-SPECIFIC UF EQUATION VARIABLES

Variable	Definition
$d_{k,n}$	Distance driven on each day.
K	Number of vehicles in data set
N	Number of days in data set
R_{cd}	Charge decreasing range.
$w_{k,n}$	Weighting applied to each day, contains a value between zero and one.

These equations are a special case of the composite UF calculation. In the case where all weights are equal to one, these equations are identical to the composite UF calculations. These equations assume that the data set results in the sum of weights and distances having a non-zero value; the total distance traveled is greater than zero. For an SUF, if a vehicle has no weighted distance, that vehicle should be removed from the data set for that cycle-specific calculation. For these SUFs, if the weighted distance traveled is zero, the SUF is undefined.

One particular option for creating SUF curves may be computed from travel surveys, such as the NHTS, using only the trip distances and trip travel times. Since only trip information is available, each trip is wholly assigned to either city or highway driving. In the NHTS, only average trip time and trip distance is available and thus an allocation must be based on calculated vehicle speed alone. For example, consider the common assumption of 55% of vehicle miles traveled (VMT) in urban settings and 45% in highway settings for partitioning trips into bins for city and highway driving. The slowest 55% of VMT is assigned to city driving. The trips that are associated with this travel are considered to be city driving samples. The remaining trips are assigned to highway driving. Figure 10 shows the cumulative VMT from the NHTS versus the average trip speed. This chart is generated by taking each trip, calculating the average speed for the trip, then sorting the list and plotting the cumulative distance versus the average trip speed. The speed below which 55% of VMT occurs is 42 mph. For illustration purposes, an additional set of SUF curves have also been included in the final coefficients table with a 43% city versus 57% highway split. More discussion regarding the two different split proportions may be found in the Federal Register, Vol. 71 No.248.

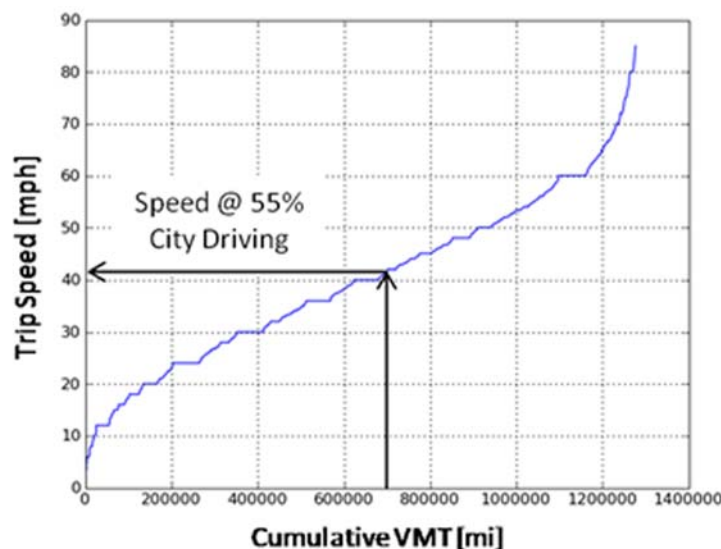


FIGURE 10 - CUMULATIVE VMT VERSUS AVERAGE TRIP SPEED

To calculate the urban weight for a day's travel, $d_{k,n}$, use

$$W_{urban,k,n} = \frac{\sum_{m=1}^{M_{k,n}} \{t_{k,n,m} \text{ if } s_{k,n,m} \leq s_{threshold}, \text{ else } 0\}}{\sum_{m=1}^{M_{k,n}} t_{k,n,m}}$$

(Eq. 9)

To calculate the highway weight for a day's travel, $d_{k,n}$, use

$$W_{highway,k,n} = \frac{\sum_{m=1}^{M_{k,n}} \{t_{k,n,m} \text{ if } s_{k,n,m} > s_{threshold}, \text{ else } 0\}}{\sum_{m=1}^{M_{k,n}} t_{k,n,m}}$$

(Eq. 10)

In either equation, if no travel occurs (e.g. $\sum_{n=1}^N t_{k,n,m}$ equals zero), the weight is assigned a value of zero. In both of these equations, the variables in Tables 3 and 4 are used.

TABLE 4 - CYCLE-SPECIFIC UF EQUATION VARIABLES

Variable	Definition
$M_{k,n}$	Number trips taken by vehicle k on day n
$s_{k,n,m}$	7.2 Average trip speed for trip m by vehicle k on day n
$s_{threshold}$	7.2.1.1.1.1 Trip speed threshold between urban and highway
$t_{k,n,m}$	7.2.1.2 Distance driven on trip m by vehicle k on day n

Using this process with the 2001 NHTS data and city/highway splits of 55/45 and 43/57 percent city to percent highway driving, the City and Highway Specific FUF curves are shown in Figure 11. As a supplement to Equations 7-10, Appendix C provides an example Python script file which can be used to parse the NHTS data and create the City and Highway Specific FUF curves discussed in this document.

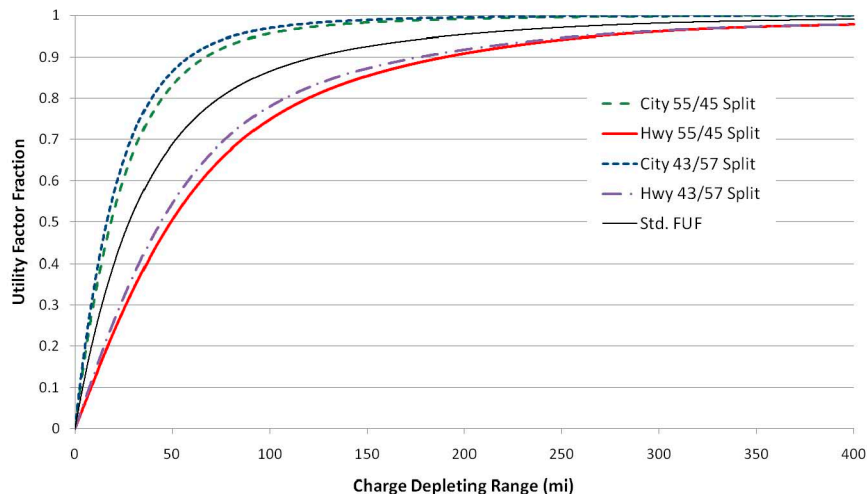


FIGURE 11 - CITY AND HIGHWAY SPECIFIC FUF VALUES

The corresponding fit coefficient table for these curves is shown in Table 5. Appendix E contains tables of the CSFUF and HSFUF equations evaluated at 1 mile increments and rounded to the nearest 0.001. For non-integer distances, it is recommended that the appropriate UF fit equation be evaluated to calculate the UF.

TABLE 5 - FIT COEFFICIENTS FOR EXAMPLE CITY/HWY SPECIFIC FUF CURVES

Value	55/45 Split - City	55/45 Split - Hwy	43/57 Split - City	43/57 Split - Hwy
norm_dist	399	399	399	399
C1	1.486E+01	4.8E+00	1.69E+01	5.43E+00
C2	2.965E+00	1.3E+01	1.84E+00	1.49E+01
C3	-8.405E+01	-6.5E+01	-9.63E+01	-8.00E+01
C4	1.537E+02	1.2E+02	1.86E+02	1.50E+02
C5	-4.359E+01	-1.0E+02	-5.60E+01	-1.26E+02
C6	-9.694E+01	3.1E+01	-1.23E+02	3.95E+01
C7	1.447E+01	-	1.99E+01	-
C8	9.170E+01	-	1.21E+02	-
C9	-4.636E+01	-	-6.30E+01	-
Max Error	0.00558	0.00387	0.00683	0.00487

7.3 Discussion Regarding the Use and Creation of Specific Utility Factors

There are numerous ways to generate the weighting for each data point, d_{kn} , and therefore many possible methods and SUF curves. Moreover, the applicability of the allocation between types of driving is only as good as the weighting method used to parse the cycles. If continuous data for driving is available, features of each driving trace can be used to determine the weighting applied to a particular data point. For example, to build a City Specific UF, the weighting for each data point could be determined from features such as number of stops, top speed, average speed, and average moving speed. Although the weighting criteria may change, the process in Equations 7 to 10 should remain the same with the exception of the threshold in Equations 9 and 10. Given the many options for creating SUF curve types, care must be taken to ensure that sufficient data exists to create a representative SUF curve and that the SUF used is appropriate for the given analysis situation.

To illustrate the breadth of options regarding methods to allocate City and Highway driving, several alternative options are presented here for discussion. The first option is similar to the previous cutoff speed method, but in this case two distinct speeds are used to differentiate between City and Highway driving style. In addition to the use of two cutoff speeds, this method assigns a City weighting between 0 and 1 according to average trip speed whereas the previous method fully allocated a trip to either City or Highway driving. For trips with an average speed above 60 mph, the trip is assumed to 100 percent Highway driving and thus receives a value of 1 for the Highway weighting and a value of 0 for the City weighting. Similarly, trips with an average speed under 25 mph are wholly assigned to City driving. Between these two cutoff speeds, trips receive a weighting that is scaled linearly between 0 and 1. In order to retain a City/Highway driving mix similar to the previous method, the City cutoff speed (25 mph) for this example was chosen to create a 55 percent City to 45 percent Highway mix relative to total miles driven. The Highway cutoff speed (60 mph) was simply chosen as a reasonable estimate. Figure 12 illustrates the weighting values as a function of average trip speed.

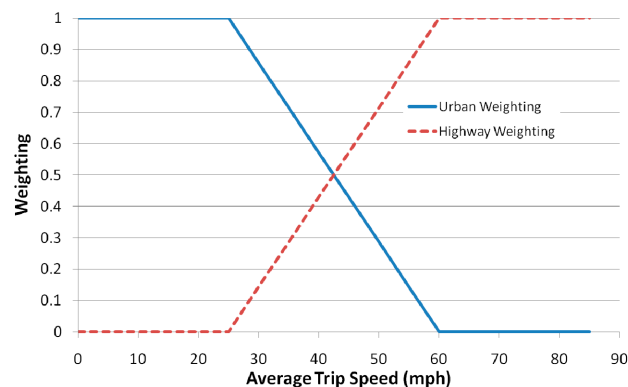


FIGURE 12 - CITY AND HIGHWAY WEIGHTS FOR ALTERNATIVE SPEED-BASED ALLOCATION METHOD

Another related method for allocating trips based on average speed is to simply create a cutoff speed for exclusively City driving and exclusively Highway. Trips between these two cutoff speeds are assumed to be equally likely to be City or Highway driving and thus are included in both the City and Highway datasets used for calculating the SUFs. This method creates two sets of overlapping data to create the City and Highway SUFs while removing the trips that are unlikely to be driven in the style of the SUF being calculated. Figure 13 illustrates the three distinct sections; the cutoff speeds shown are used for example only and would need to be adjusted depending on the desired amount of overlap between City and Highway driving. In this example, the actual mix of City and Highway relative to VMT is unknown due to the overlapping region.

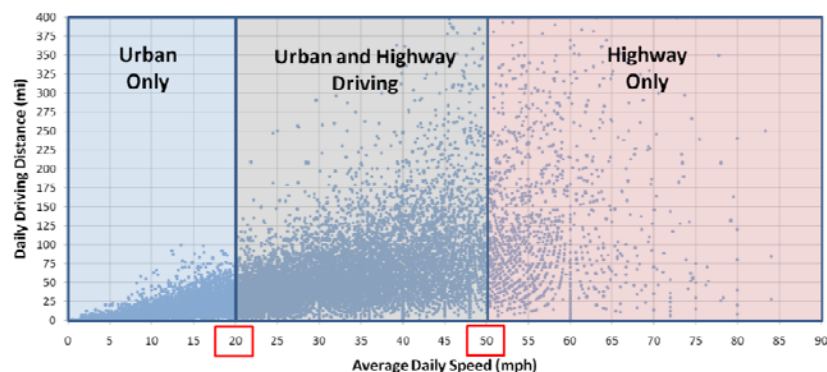


FIGURE 13 - DRIVING STYLE SECTIONS FOR OVERLAPPING DATASET ALLOCATION METHOD