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Alternative utility factor versus the SAE J2841 standard method for PHEV and BEV applications

Elena Paffumi *, Michele De Gennaro, Giorgio Martini

European Commission, Joint Research Centre, Directorate C, Energy, Transport and Climate, Via Enrico Fermi 2749, Ispra, VA, 21027, Italy

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ABSTRACT

This article explores the potential of using real-world driving patterns to derive PHEV and BEV utility factors and evaluates how different travel and recharging behaviours affect the calculation of the standard SAE J2841 utility factor. The study relies on six datasets of driving data collected monitoring 508,607 conventional fuel vehicles in six European areas and a dataset of synthetic data from 700,000 vehicles in a seventh European area. Sources representing the actual driving behaviour of PHEV together with the WLTP European utility factor are adopted as term of comparison. The results show that different datasets of driving data can yield to different estimates of the utility factor. The SAE J2841 standard method results to be representative of a large variety of behaviours of PHEVs and BEVs' drivers, characterised by a fully-charged battery at the beginning of the trip sequence, thus being representative for fuel economy and emission estimates in the early phase deployment of EVs, charged at home and overnight. However the results show that the SAE J2841 utility factor might need to be revised to account for more complex future scenarios, such as necessity-driven recharge behaviour with less than one recharge per day or a fully deployed recharge infrastructure with more than one recharge per day.

1. Introduction

The large scale deployment of electrified vehicles in cities will play a key-role in improving air quality in densely populated areas in the next years, limiting the negative effects of human exposure to air and noise pollution from transport and reducing the Greenhouse Gases (GHGs) emissions. At a European level, this calls for substantial changes in the mobility plans in urban conglomerates, following the guidelines outlined by the EC White Paper 2011 (European Commission, 2011), the Strategy and Action Plan for creating an Energy Union (European Commission, 2015b) and the European strategy for low-emission mobility (European Commission, 2016a).

In such context, Plug-In Electric Vehicles (PHEVs) represent an intermediate technological steps between the conventional fuel and the Battery Electric Vehicles (BEVs), combining the advantages of both these technologies. These vehicles are capable of driving in both charge depleting (CD) - pure electric mode driving, or charge sustaining (CS) -pure conventional fuel mode driving, depending on the configuration of the driveline, the characteristics of the driving profile and the vehicle charging frequency. The share between CD and CS in respect to the total distance driven determines the environmental performance of the vehicle, and it is usually expressed as the Utility Factor (UF). It can range from 0, i.e. a conventional vehicle or HEV that drives only in conventional fuel mode, to 1, i.e. PHEV and BEV that drives only in electric mode. The UF definition is standardised in the SAE J2841 (SAE International, 2010), where a calculation method based on data collected from travel surveys of conventional fuel vehicles is presented, assuming that each vehicle begins the first trip of the day fully-charged and does not charge until the last trip of the day. The standardised SAE J2841 UF is used in a variety of applications for the calculation of PHEV environmental performance, such as:

- energy consumption and CO2 emissions assessment for type approval of vehicles (UNECE, 2007, 2015, European Commission, 2016b);
- cost-benefit evaluation of PHEVs (Bradley and Frank, 2009);
- fuel economy labelling purposes (Bradley and Quinn, 2010; Nevers, 2011; Enviromental Protection Agency (EPA), 2010; Environmental Protection Agency EPA and National Highway Traffic Safety, 2010);
- PHEV fleet fuel economy credit calculations, e.g. Corporate Average Fuel Economy (CAFE) regulations (U.S. Department of Transportation, 2009) and California ZEV credit calculations (California Enviromental Protection Agency, 2011).

* Corresponding author.
E-mail address: elena.paffumi@ec.europa.eu (E. Paffumi).

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Nomenclature

Acronyms

AC	Alternating Current
BEV	Battery Electric Vehicle
CAFE	Corporate Average Fuel Economy
CATI	Computer-Aided Telephone Interviewing
CD	Charge Depleting
CS	Charge Sustaining
CSFUF	City Specific Fleet Utility Factor
DC	Direct Current
EPA	Environmental Protection Agency
EU	European Union
FUF	Fleet Utility Factor
GHG	Greenhouse Gas
GPS	Global Positioning System
GTR	Global Technical Regulation
HDV	Heavy Duty Vehicle
HEV	Hybrid Electric Vehicle
HSFUF	Highway Specific Fleet Utility Factor
HVAC	Heating, Venting and Air Conditioning
ICE	Internal Combustion Engine
IUF	Individual Utility factor
LDV	Light Duty Vehicle
IEC	International Electrotechnical Commission
MDIUF	Multiple Day Individual Utility Factor
NHTS	National Household Transportation Survey
PHEV	Plug-in Hybrid Electric Vehicles
SDIUF	Single Day Individual Utility Factor
SFH	Specific Fleet Highway
SFU	Specific Fleet Urban
SUF	Specific Utility Factor
SOC	State of Charge
UF	Utility Vehicle
VMT	Vehicle Miles Travelled

Some studies have published alternative PHEV UF to SAE J2841 (Bradley and Quinn, 2010; Bradley and Davis, 2011), exploring how varying the key assumptions in the standard SAE method can influence the UF results. These studies based on travel survey data have shown that the UF of PHEVs changes as a function of their annual distance driven, therefore using the standard daily mileage UF to calculate an equivalent fuel economy results in an inconsistent set of assumptions. Only few contributions can be found relying on more accurate data sources such as navigation system data. In this respect some results can be found in (Neubauer et al. (2013)) where GPS-data from 398 conventional fuel vehicles with 3 months observation period has been used to estimate cost performance of different vehicles or in Wu et al. (2015), where GPS-based longitudinal travel data covering 3–18 months and collected from 403 vehicles in the Seattle metropolitan area have been analysed showing that the workplace charge opportunities significantly increase UFs if the CD range is no more than 40 miles and that the price of gasoline and the available charging time do not have significant impact on the UFs, compared with the simple assumption that the battery is always full before leaving home or workplaces. This last work (Wu et al., 2015) examined similar conditions to those that will be presented in this work, but it refers to USA driving patterns and focus on one geographical region only, i.e. Seattle. Some other studies have instead focused the attention on real-world PHEV data, to evaluate to which extend the standard UF estimated from ICE survey data resemble the real-world behaviour of PHEV users. For example 2000 PHEV have been observed for more than one year in the U.S. and Germany in (Plötz et al. (2015, 2017)), to estimate real-world fuel economy, recognising as main influencing factors the annual mileage, the regularity of daily driving, and the likelihood of long-distance trips. Dutch refuelling data which includes an important group of business users who hardly charge has been analysed in Ligterink and Eijk (2014) and Ligterink et al. (2013) finding that PHEV users drive in pure electric for 15-to-30% of the total daily distance. Actual versus estimated UF has been studied in Smart et al. (2014) for a large set of privately owned Chevrolet Volts, showing that Volt drivers achieved higher percentages of distance travelled in EV mode because of fewer long-distance travel days than drivers in the national travel survey referenced by the SAE J2841 and because they charged more frequently than the SAE J2841 assumption of once charge per day (~1.4 charging events per day).

The aim of this study is to contribute further to the UF assessment, exploring the use of large data set of real-world navigation system data of conventional fuel vehicles from several geographic areas in Europe, thus examining the sensitivity of the standard UF calculation method to different driving behaviours, different technologies of PHEV and BEV, combined with different recharging constraints, developed in previous work of the authors (Paffumi et al., 2015b). The UF concept is under continuous development (Douba, 2010) and this proposed work attempts to capture some aspects that can guide further the improvement of the UF calculation and application of the UF to PHEV policy. An improved UF can contribute to complement carbon emissions and alternative transport fuels assessments, such as those reported in (Nocera and Cavallaro (2016), He and Chen (2013), von Brockdorff and Tanti (2017) and Lutsey (2012)).

The analyses in this work are firmly grounded on six databases of driving patterns collected by GPS in six European cities (Octo Telematics Italia S.r.l., 2013; Be-Mobile, 2007; Universalis, 2011):

- Modena and Firenze (IT);
- Amsterdam (NL);
- Brussels (BE);
- Luxemburg (LU);
- Paris (FR);

consisting in 508,607 monitored vehicles, equivalent to approximately 9 million trips and parking events. The data is also complemented by a seventh database of synthetic urban travel data that is, traffic simulation data, for the city of Cologne (DE) (TAPAS Cologne Project, 2011). The data processing and the UF calculation have been performed with a module implemented in the multi-purpose data mining and processing platform TEMA (Transport tEchnology and Mobility Assessment platform) (European Commission, Joint Research Centre, 2012), developed by the authors since 2012, whose results have been published in several articles, i.e. (De Gennaro et al., 2014a, c, 2015a, 2016a, b; Paffumi et al., 2016; Paffumi et al., 2015b; Martini et al., 2014; European Commission, 2015a). The computed UF, both standard and alternative, are then compared to the GTR 15 WLTP (UNECE, 2015) UF curve and to the real-world UF from actual driving data of PHEVs (Spritmonitor.de, 2001; voltstats.net, 2011) and (Plötz et al., 2015) to estimate to which extend the computed UF and standard method can represent the real-world driving behaviour of PHEVs and explore the necessity of future revision of the standard method, when more PHEV data will be available because more PHEV will be on the market. A BEV UF is also derived following the method introduced in Duoba (2013), to explore the electric drive capability for a given battery electric vehicle range versus a given