



On the distribution of individual daily driving distances



Patrick Plötz^{a,*}, Niklas Jakobsson^b, Frances Sprei^b

^a Fraunhofer Institute for Systems and Innovation Research ISI, Breslauer Str. 48, 76139 Karlsruhe, Germany

^b Chalmers University of Technology, Energy and Environment, 412 96 Göteborg, Sweden

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ABSTRACT

Plug-in electric vehicles (PEV) can reduce greenhouse gas emissions. However, the utility of PEVs, as well as reduction of emissions is highly dependent on daily vehicle kilometres travelled (VKT). Further, the daily VKT by individual passenger cars vary strongly between days. A common method to analyse individual daily VKT is to fit distribution functions and to further analyse these fits. However, several distributions for individual daily VKT have been discussed in the literature without conclusive decision on the best distribution. Here we analyse three two-parameter distribution functions for the variation in daily VKT with four sets of travel data covering a total of 190,000 driving days and 9.5 million VKT. Specifically, we look at overall performance of the distributions on the data using four goodness of fit measures, as well as the consequence of choosing one distribution over the others for two common PEV applications: the days requiring adaptation for battery electric vehicles and the utility factor for plug-in hybrid electric vehicles. We find the Weibull distribution to fit most vehicles well but not all and at the same time yielding good predictions for PEV related attributes. Furthermore, the choice of distribution impacts PEV usage factors. Here, the Weibull distribution yields reliable estimates for electric vehicle applications whereas the log-normal distribution yields more conservative estimates for PEV usage factors. Our results help to guide the choice of distribution for a specific research question utilising driving data and provide a methodological advancement in the application of distribution functions to longitudinal driving data.

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1. Introduction

Plug-in electric vehicles (PEVs) charged with renewable electricity are a possible way of reducing greenhouse gas emissions from the transport sector without abandoning individual car-based mobility (Chan, 2007). But the limited electric driving range of battery electric vehicles is a major hurdle for many consumers and the electric range of hybrid PEVs strongly impacts the PEVs utility (Plötz et al., 2014). This limited electric driving range has brought more attention to the distribution of individual vehicle kilometres travelled (VKT) (Greene, 1985; Pearre et al., 2011; Smith et al., 2011; Lin et al., 2012; Tamor et al., 2013). Several studies choose specific distribution functions for analysing and modelling driving vehicle usage, but the choice of a distribution and its consequences have not yet been fully understood nor systematically analysed.

* Corresponding author.

E-mail address: patrick.ploetz@isi.fraunhofer.de (P. Plötz).

Table 1
Overview of data sets.

Name of data set	German Mobility Panel	Swedish data	Winnipeg data	Settle data
Location	Germany	Sweden	Canada	USA
Collection method	Questionnaire	GPS	GPS	GPS
Sample size	6339	429	72	420
Avg. observation period	7 days	58 days	216 days	251 days

Several studies provide evidence that individual-longitudinal and cross-sectional VKT distributions are peaked and right skewed such as the Weibull, log-normal and Gamma distribution. [Greene \(1985\)](#) and [Lin et al. \(2012\)](#) analyse two sets of data and argue that the Gamma distribution is most suitable ([Greene, 1985](#); [Lin et al., 2012](#)). However, [Blum \(2014\)](#) and [Plötz et al. \(2012\)](#) argue that the log-normal distribution provides the best fit for most drivers and for all daily VKT. [Pearre et al. \(2011\)](#) empirically analyse days with long-distance driving and find the travel pattern of individual vehicles does not resemble the average fleet travel pattern. [Smith et al. \(2011\)](#) use individual vehicle travel data to construct an average commuter driving cycle. Finally, [Tamor et al. \(2013\)](#) use a mixture of a normal and exponential distributions with five free parameters to model vehicle specific daily VKT distributions.

Overall, the evidence for the best two-parameter distribution for daily VKT is not conclusive. Furthermore, the word 'best' is in this context highly application-dependent. A certain distribution may be performing overall better than another according to some goodness of fit measures, but be worse when it comes to predicting short or long daily driving distances. This is especially important in the context of PEVs where research often focuses on the utility factor (UF) of PHEVs, see e.g. [Gonder et al. \(2007\)](#), [Millo et al. \(2014\)](#), [Silva et al. \(2009\)](#), [Smart et al. \(2014\)](#), or the days with long-distance travel, i.e. days requiring adaptation (DRA), for BEVs, e.g. [Jakobsson et al. \(2016\)](#), [Tamor and Milacic \(2015\)](#), [Greene \(1985\)](#), [Pearre et al. \(2011\)](#), [Smith et al. \(2011\)](#), [Lin et al. \(2012\)](#), and [Tamor et al. \(2013\)](#). The UF of PHEVs depends on the short daily driving distances, while the DRA depends on the long daily driving distances; in both of these cases, the choice of distribution impacts the results obtained.

The aim of the present paper is to provide a systematic comparison of the choice of distribution function for individual daily VKT with respect to (1) goodness of fit and (2) predictive power of DRA for BEVs and UF for PHEVs. We use four different data sets, with various complementary properties, to analyse the three two-parameter probability distributions with respect to daily driving data that received most attention in the literature. The three distributions are log-normal, Weibull and Gamma. We use three GPS measured data sets from Western Sweden; Winnipeg, Canada; and Seattle, USA; respectively. The fourth data set is survey based and from Germany. The data sets differ in sample size and measurement length, which provide robustness to our results. Furthermore, we analyse the effect of measurement length on the stability of goodness of fit, and overall best distribution.

The present paper differs from previous work in several aspects. First, we test the assumption of independently and identical distributed (iid) observations underlying the use of distribution functions for daily mileages. Second, we perform a systematic comparison of several data sets. Third, we analyse the effect of observation period on the goodness of fit for the distribution functions. Fourth, we compare the consequences of distribution choice in applications related to PEV.

2. Data and methods

2.1. Data

We use four data sets to analyse the goodness of fit of different distributions. The data sets comprise vehicle motion from Germany ([MOP, 2010](#)), Sweden ([Karlsson, 2013](#)), Canada ([Smith et al., 2011](#)) and the USA ([PSRC, 2008](#); [Transportation Secure Data Center, 2015](#)). The average observation periods range from 7 to more than 200 days. The different data sets are summarised in [Table 1](#). A description of the data sets follows below. More detailed summary statistics are given in [Table 2](#).

The German Mobility Panel ([MOP, 2010](#)) is one of two national household travel surveys in Germany. Since MOP is a household travel survey which focuses on people and their trips, we assigned trips to vehicles if unambiguously possible (see [Kley, 2011](#) and [Plötz et al., 2014](#) for details). By using all data from 1994 until 2010, we obtain 6339 vehicle driving profiles with 172,978 trips in total. Apart from driving, the profiles contain socio-economic information about the driver (e.g. age, sex, occupation, household income, education) and the vehicle (e.g. size, owner, garage availability). This data set is representative for German driving in terms of daily and annual mileage, vehicle size and garage ownership ([Gnann, 2015](#)).

The Swedish Car Movement Data (SCMD) consists of GPS measurements of more than 700 privately driven cars in the provinces of Västra Götaland and Kungälv in Western Sweden. Of these, we have selected 429 cars that have at least 30 days of good GPS measurements, whereas the rest have less than 30 days and are not included in the analysis (for details see [Björnsson and Karlsson \(2015\)](#)). Measurements were evenly distributed over the years 2010–2012. The cars were randomly sampled from the Swedish vehicle registry with an age restriction on the car of maximum 8 years, the positive response rate of the selected households was 5%. Western Sweden is representative for Sweden in terms of urban and rural areas, city sizes and population density. The sample is representative in terms of car size and car fuel type. There is a slight overrepresentation of measured cars having higher annual VKT cars in the households compared to the national average due

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