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The Swedish car movement data project

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Abstract To facilitate a well-informed and efficient transition to electrified vehicles, such as PHEVs, information about individual vehicle's movements over longer time periods is needed. This is of major importance for optimal battery design, estimation of consumer viability and assessment of the potential for PHEVs to shift energy use in transport sector from fuel to electricity. Good and publicly available data of this kind is today unfortunately lacking. The aim of this project has been to gather a larger amount of data on the characteristics and distribution of individual movements for privately driven cars in Sweden by measurement with GPS equipment. The logging was performed with commercial equipment containing a GPS unit, including a roof-mounted antenna, and a gprs communication unit. Data logged were: time, position, velocity, and number and id of used satellites. The measurement started in June 2010 and ended in September 2012. The target is to accomplish good quality measurements of at least 30 days for about 500 representative vehicles. All data is not yet processed but in this paper initial statistics is offered to present important areas of use and possibilities for future work.

Keywords: GPS measurement, car movement pattern, PHEV, Sweden

1 Introduction

Possibilities to reduce greenhouse gas emissions, rising oil prices and concerns about energy security are important factors increasing the interest for various kinds of electric vehicles. Due to, among other things, the expensiveness of batteries and driver's range anxiety, plug-in hybrid electric vehicles (PHEVs) have been suggested as a compromise between cost, performance and range. PHEVs are already today present on the market but to facilitate a well informed and efficient transition to electrified vehicles, such as PHEVs, knowledge on the actual movement patterns of individual vehicles is needed. Information about the distribution of vehicle's movements over longer periods is of major importance for optimal battery design, estimation of consumer viability and assessment of the potential for PHEVs to shift energy use in transport sector from fuel to electricity [1, 2, 3]. Comprehensive datasets on car movements are also needed for simulation and optimization of powertrains and software development [4].

Today however there is a lack of publicly available good quality data on car movement patterns. Needed is improved data on the distribution of trip lengths and trip characteristics, such as speed and orography, to be able to determine the possible energy use for individual trips and thus possibility to analyse need for battery capacity. Also knowledge of time and duration both for trips and parking in between trips is important to understand the possibilities for charging and potential impact on the electricity grid.

National or regional travel surveys are regularly gathered in many countries. However, in most cases, as in Sweden [5], there is no tracking of cars' movements but of persons' only, and in many cases the measurement period is limited to one day or a week. The quality of this often self reported (using questionnaires or interviews) data has also been recognized to give an underestimate of the travelling, due to a certain share of non-reported trips [6,7]. Neither does this type of data give the exact position of the vehicles trips and their stops. GPS-assisted travel surveys have been discussed in several countries but are so far uncommon [8]. To better capture an individual vehicles movement pattern it is also important to gather data for a longer time period. This since the travel patterns of individuals varies considerably over time [9].

Continuous measurement of time, speed and position with GPS (Global Positioning System) equipment offers a possibility to gather more thorough information on car movement. A drawback with this type of data collection is the lack of information about the purposes of the trips (often available in travel surveys). This can to some extent be aggregated from the available positioning data. However doing this with some degree of quality needs some effort and additional information about workplace locations etc. [6].

The aim of the project described in this paper has thus been to gather a larger amount of data on the characteristics and distribution of individual movements for privately driven cars in Sweden by measurement with GPS equipment.

It can be argued that measurement of today's car movement will not be representative for tomorrow's battery electric vehicles. These are in the near future probably very limited by range and will therefore be used differently than today's cars, maybe only in cities or as second car. However, for plug-in hybrid electric vehicles the range will not be as great a concern and it can be a reasonable assumption that these vehicles will be used in similar way as today's car. In countries like Sweden, with a fleet of for European conditions relatively large cars and also less subject to traffic jams, PHEVs will be the dominant electric vehicle type, according to many expert judgments. Therefore the movement patterns of current conventional vehicle fleet are of considerable interest.

Most direct measurements of car movements with for instance GPS equipment have been sparse, for specific purposes, or focusing vehicles in specific areas. Earlier measurements include for example a tracking of cars for one day each, which were performed in St Louis [11]. Puget Sound Regional Council in the Seattle area, performed from November 2004 to April 2006 a logging with GPS of 450 vehicles from 275+ volunteer households recruited among potential participants before and after (hypothetical) tolls were charged for use of major freeways and arterials in the Seattle metropolitan area [12]. Another example is Commute Atlanta, a Georgia tech project with GPS measurements of commuting in the Atlanta area where the main objective of the program was to assess the effects of different cost schemes. The first phase of the project included a measurement of 445 cars owned by 273 households for up to one year for studies of travel behaviour [13]. The data collected in St. Louis, Seattle and Atlanta have each independently been used in different assessments of viability of either BEVs or PHEVs [3, 14, 15]. Travel surveys in US with GPS, not directly focusing on cars, have been performed or are planned in, Baltimore, Washington, Chicago, and California [16-19]. In Australia cars have been tracked for the purpose of investigating driver behaviour such as speeding [20, 21]. In Italy a unique commercial dataset for car movements are from the GPS tracking of currently around 650 000 cars for insurance profiling performed by the company Octotelematics [22]. In Canada, Department of Geography at University of Winnipeg within the AUTO21 program, has been logging 76 cars in Winnipeg with GPS at one-second intervals for up to 12 months, to be able to, for instance, assess the prerequisites for electrification with PHEVs. A further logging of 50 rural vehicles often commuting into Winnipeg has also been performed. [23, 24, 25]

In Sweden datasets with GPS tracking are available for a small set of only 29 cars logged for about two weeks for the purpose of driving behaviour – emissions modelling verification [1]. In this case equipment was installed in 5 specifically prepared vehicles, which then were placed in 29 families, where they substituted a car of similar size. In another measurement for the evaluation of the impact and acceptability of Intelligent Speed Adaptation (ISA) equipment about 200 cars were tracked for roughly 100 days [2]. Although valuable, both these datasets are covering limited geographic regions and are at this moment around ten years old.

2 Method

2.1 Selection of vehicles

In nine campaigns a total of 700 cars have had measurement equipment installed for about two months each. The first campaign started in June 2010 and the last ended in September 2012. Before each campaign, for request of participation, cars where drawn randomly from an excerpt of cars from the Swedish motor-vehicle register, Table 1.

Passenger cars of type I are cars mainly aimed at person transport and excludes campers [26, 27]. Vehicles, which, according to the vehicle register, are used in commercial traffic, such as taxicabs, are not included in the excerpt due to the focus on privately driven cars. The excerpt is also restricted to cars of model year 2002 and younger. Electric vehicles, of which only a few exist though, are excluded, due to their range limitation and therefore possible specific movement pattern. There are also ongoing other projects dedicated to various measurement on electric vehicle and their driving and charging.

Table 1: The excerpt of cars from the Swedish motor-vehicle register.

Parameter	**Selection**
Type of vehicle	Passengers cars, type I
Use of vehicle	Non-commercial vehicle
Model year	Car model 2002 and younger
Region in Sweden	Registered in Västra Götaland county or Kungsbacka municipality

Cars owned by companies or public institutions may be used in specific ways dependent on the situation specific for each vehicle, for instance, to transport personnel between patients in the eldercare. Use patterns of these cars are less representative and can sometimes be reasonably gathered by other means and have therefore not been included in this study focusing on privately driven cars.

The cars in the Swedish motor-vehicle register are owned or leased by either a juridical person or a natural person. For the excerpt described in Table 1, the share of juridical persons is almost 12 %. A large share of these cars is company cars, that is cars leased or owned by companies or institutions but to a large extent used by a person for his/her private driving. Roughly every second new car in Sweden is a company car. They are normally kept for 3 years, before entering the private car market as used cars. Company car is a fiscal term rather than administrative so there is no details on cars being company cars in the motor-vehicle register. A company car is seen as a fringe benefit in the Swedish income tax return if used for private driving more than 10 times a year or more than 1000 km/yr. Since the fringe benefit is relatively high and independent of the amount of private driving it is not favourable to the user if he/she drives too little. Also the running costs can be lower if the company pays for the fuel. If so, 120% of the fuel cost is seen as a tax fringe, which means that with current tax rules a person with such a benefit generally pays only 60% of the fuel cost compared to other drivers [28]. It is therefore reasonable to assume that these cars are chosen and driven by persons who expect to drive and will drive more than the average driver. In this study we extract the company cars by addressing the inquiry letter to the driver of the specified car and ask if it is a company car. When so, it is of interest to the project. Also cars registered as owned by a natural person can be a car owned by a private firm and not used for private driving. Again the initial inquiry was used to ask if the car is privately driven. (Also, a confirmation of the private driving could be achieved through the questionnaire accompanying the measurement, where some household data were asked for.)

Only relatively new cars were targeted to focus on the part of the car lifetime that is most influential for economic viability considerations and the purchase decision for a new car. As the study and selection is stretched out over more than two years, the registration date has been successively shifted toward later dates thus keeping constant the age of the oldest cars in the selected fleet. Initially for the first period the registration date is set to March 1, 2002 and younger. In the last campaign cars are not older than February 1, 2004. This selection of younger cars constitutes roughly 45% of the total car fleet and 60% of the total distance driven [29]. For cars older than in the selection the market value has sunk even more. Thus the selection represents a major share of the total economic value of the car fleet.

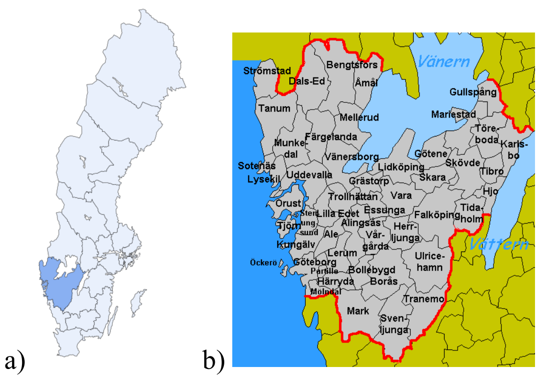


Figure 1: The selected region for the Swedish car movement data project, a) the Västra Götaland county is marked in darker blue on this map of Sweden; b) A larger map of Västra Götaland county with its 49 municipalities. The Kungsbacka municipality in the county of Halland, also included in the selected region, is the uppermost coastal municipality on the west coast south of Västra Götaland.

The extracted cars are registered in the county of Västra Götaland or in Kungsbacka municipality. The region is located in South-West of Sweden and has about 1.6 million inhabitants and 0.75 million cars (roughly 1/6 of Swedish totals, respectively). The region has a variation of larger and smaller towns and rural areas, which is fairly representative for Sweden in general. It also includes Gothenburg, the second-largest town of Sweden. Very sparsely populated areas more commonly found in the north of Sweden is lacking, which is reflected in the region's population density of around 65 inhabitants/km^2; three times the average for Sweden, but reasonable representative for the southern parts of Sweden where most of the inhabitants live.

The random selection is stratified into 14 groups along five parameters, which are known or thought to statistically influence the car movement patterns, Table 2. The cars are divided into privately owned cars and cars owned by juridical persons, the two categories available in the motor-vehicle register. The juridical cars focused here, the company cars, are supposed to possibly have another movement pattern then private cars, as described above. The diesel car is more expensive than the corresponding gasoline model, while the operating costs are lower due to the more energy efficient engine and also cheaper fuel per energy unit. This leads to an expected considerably larger yearly driving for diesel cars, which is also reflected in the statistics [30]. The diesel cars have almost twice the driving distance compared to gasoline cars. Due to the relatively recent interest in the diesel cars, these are also newer which should explain part of the difference.

Table 2: The applied stratification of the vehicle selection into 14 groups.

Fleet	**Stratification parameter**					**Strata designation**	**Statistical share**[d]
	Ownership	***Geographic area***[a]	***Fuel***	***Car age***[b]	***Kerb weight***[c]		
Selected fleet	Natural person[e]	Gothenburg, Mölndal, Partille	All other fuels[f] (AOF)	Young	Heavy	GB7T	1.26
					Light	GB7L	4.36
				Old	Heavy	GB6T	5.66
					Light	GB6L	10.28
			Diesel	Young		GD7	3.02
				Old		GD6	1.89
		Remaining region	AOF	Young	Heavy	ÖB6T	3.14
					Light	ÖB6L	7.70
				Old	Heavy	ÖB7T	14.47
					Light	ÖB7L	20.93
			Diesel	Young		ÖD7	8.13
				Old		ÖD6	7.17
	Juridical person[d]		AOF			JB	6.33
			Diesel			JD	5.67

[a] Place of registration: Gothenburg, Mölndal and Partille are the three more densely populated municipalities in and around Gothenburg.

[b] Car model year: Young = model year 2007 and younger. The registration date is successively adjusted for the selections to later campaigns.

[c] Kerb weight (vehicle mass + 75 kg for driver): Heavy means ≥ 1500 kg.

[d] Since data from the last two campaigns are not yet fully processed, the statistical share after measurement has not yet been established

[e] 30 % of the vehicles owned by a juridical person are initially assumed not to be privately driven to a large extent. Corresponding figure for vehicles owned by a natural person are assumed to be 3%.

[f] Except electricity. In the end of April 2012, there were in the geographic area in question 81 electric vehicles registered of model year 2003 and newer, of which 79 were registered for juridical persons.

The cars are stratified geographically in two groups: those situated in or around Gothenburg and the rest of the selected area. The Gothenburg area includes the municipalities of Partille and Mölndal, which are indivisible parts of the town area. It is assumed that the movement pattern in this larger town area can possibly differ considerably from the rest in various aspects.
Since younger cars are used more intensively than older ones [30], the cars are stratified along age in two groups: older and younger than 40 months, respectively.

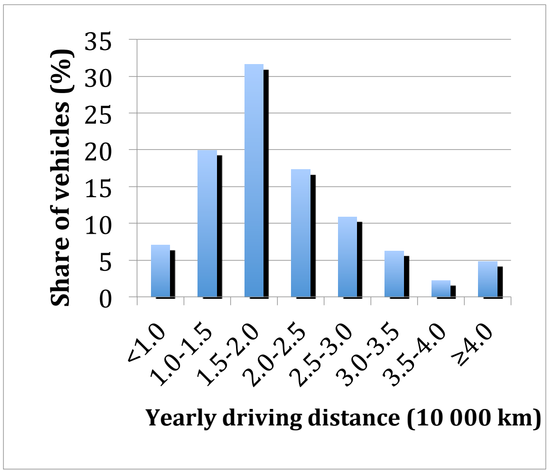


Figure 2: Stated yearly driving distance of logged cars.

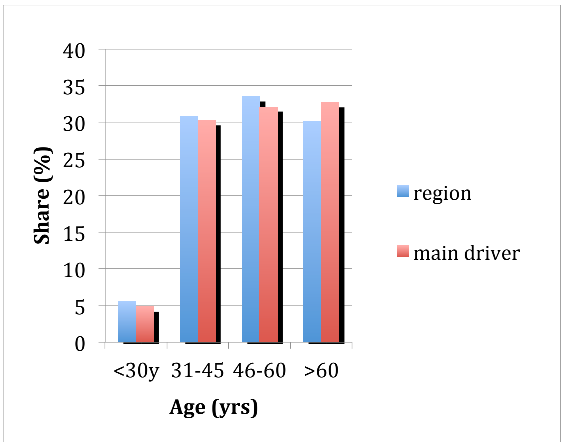
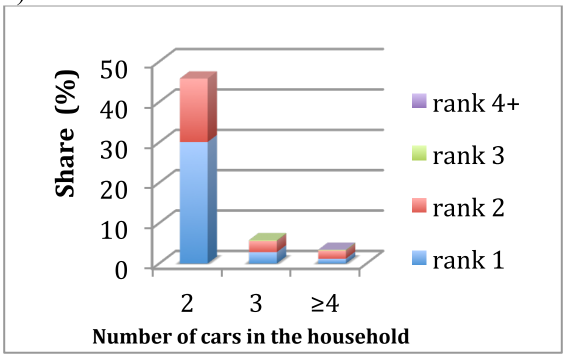


Figure 3: Stated age of main driver of logged cars and age of car owners in the region.

For each randomly picked vehicle from the excerpt, a request letter with an inquiry to participate in the measurement was sent by mail to the car owner/driver. Overall around 12 360 request letters have been sent in 9 batches. (This corresponds to about 3.5 % of the privately driven cars in the region. A check for a doubling of the requests have not been made, so unfortunately there must be quite some among these persons who have got two or more inquiries.) The average positive response frequency on the inquiry was about 7.5 %. This rather low positive response frequency might have affected the composition of the measured fleet.

a)



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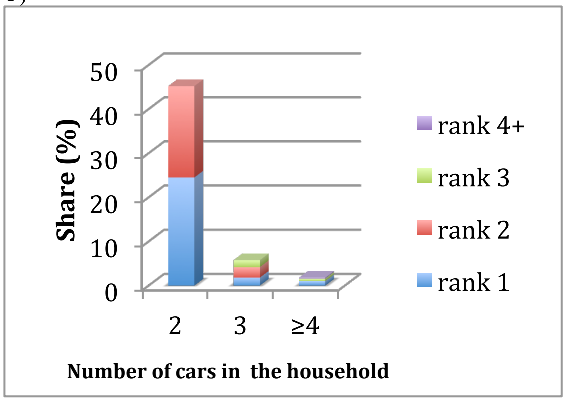


Figure 4: For logged vehicles belonging to household with more than one cars, share of stated rank among the household's cars of a) yearly driven distance (longest = 1) and b) size (largest = 1), respectively.

A questionnaire that was sent to all participants and with a response frequency of over 93 %, gives some data on the measured cars, their drivers and households. (The results here are from the roughly first 500 of the 700 participants.) The stated yearly driving distances of the cars are presented in Fig 2. The average driving distance of 18700 km is somewhat larger than the average for 1 to 9 years old cars in Sweden (16800 km) [30]. The age distribution of the main driver is close to the ownership in the region, Fig 3. The ranking within the household of yearly driving distance (longest = 1) and of size (largest = 1) of the logged car are given in Fig 4. The size of logged vehicles are close to the median in the household, while the yearly driving distance is somewhat larger than the household median, which is reasonable when the logged cars belong to the youngest half of the fleet. The driving will be influenced of among other things of the number of persons and the number of driving licences in the household. 15 and 70%, respectively, of the households have one and two adults (i.e., members 18 yrs or older) in the household, Fig 5. Of the cars, 61 % are in households without children. For most households all of the adult persons have a driving license, Fig 6. (We are naturally not targeting households without a licence).

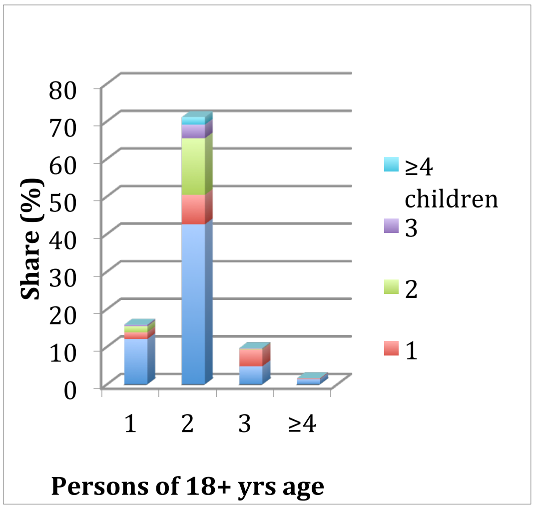


Figure 5: For the logged cars, the stated share of number of children (< 18 yrs old) in households with various numbers of adult persons.

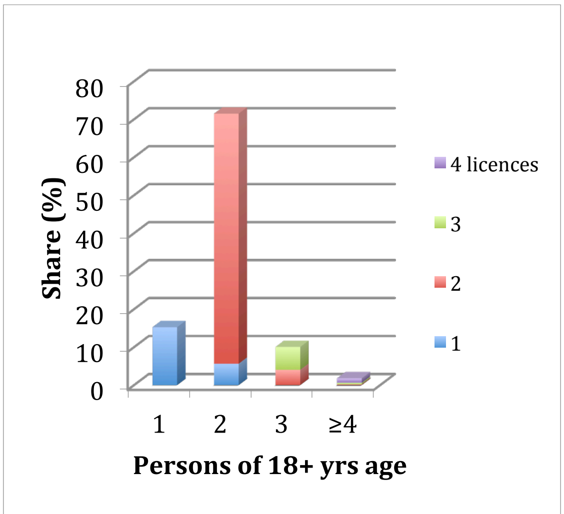


Figure 6: For the logged cars, the stated distribution of number of driving licences in households with various numbers of adult persons.

2.2 The logging equipment

The logging was performed with commercial equipment containing a GPS unit, including a roof-mounted (magnetic holder) antenna, supplied from the 12V outlet in the car, Fig 7. By avoiding a more advanced connection through the CAN bus the risk to interfere with the cars electronic system was prevented. The system is simple enough to be sent to the car owner/driver by ordinary mail services for installation by her/himself.

Figure 7: The GPS equipment is contained in a box with antenna for gprs communication and supported with a GPS antenna (left) and plug for 12 V outlet.

The signals logged (2.5 Hz frequency) were:
- Timestamp (current and last valid),
- Position (latitude, longitude and altitude),
- Velocity (speed and direction),
- Used satellites (number and identity),
- Dilution of precision (pdop, hdop, vdop).

The logged data was continuously transmitted (after intermediate storage on a micro SD-card situated in the equipment box) on the mobile network (gprs) for intermediate storage on a server. The micro-card storage allows for storing data for a longer period without contact with the mobile network. This feature has enabled also movement patterns collected abroad to be gathered. The gprs communication is bidirectional making updating of the software and control of the equipment possible.

2.3 Storage and post processing of data

The raw data were finally stored in an SQL database at Test Site Sweden (TSS), a Swedish national resource for demonstrations and validation of research results, focusing among other things on electric and hybrid vehicles [31]. The raw data format is sometimes unnecessary cumbersome to work with. Therefore also a processing of the raw data has been performed to provide the material in a more accessible format. The result is stored in

yet another SQL database, an “analysis database”, at TSS.
The analysis database holds data on three levels. The first level contains second by second data similar to the raw data but now smaller apparent anomalies are corrected and the data is organised into trips. Absence of loggings for more than 10 seconds will denote the start of a new trip, while shorter gaps of data in between loggings will be interpreted as a data loss and values will be interpolated. The choice of 10 seconds is set deliberately low to allow users to decide on their own partitioning into trips.
The second level provides statistical data for each trip such as trip starting/ending times and locations, travelled distance, averages of speed, of speed squared, and of speed cubed, trip duration, number of interpolated data gaps and values. The third level holds statistical data for each device/vehicle such as total distance travelled during measurement period, time of first/last measurement, average speed for all driving, total number of trips etc.
Of course the first level is enough to reproduce the second and third level but the purpose of this division is to allow for easier access of the data. Some areas of use will demand detailed knowledge on a second by second level (as in [4]), while in other areas it might be enough with good information on trip lengths and break times (as in [32]).
Further post-processing of the positional data is planned to achieve enhanced data quality and allow for more correct and easier assignment of data to the national road database. The accuracy for the used type of GPS equipment should be a few meters for non-disturbed conditions. Still this can be a problem for accurate assignment to the correct road, especially in urban or other environments with parallel or crossing overhead roads [33]. Also, in urban canyons the accuracy can be much less due to signal scattering. The intended post-processing will utilize SWEPOS, the Swedish national network of permanent reference stations for GPS. Also, the horizontal accuracy is expected to increase to around one meter [34]. This will enhance the possibility of, for instance, a more accurate derivation of the instantaneous power needs of the driving, useful for example in detailed simulations of vehicle energy management.
The data is available for research concerning energy and environment, safety, and traffic planning and can be accessed at a TSS website [35]. Due to the privacy character of some of the data, the availability will be classified according to type.

3 Resulting data from the measurements

During two years more than 700 cars have installed logging equipment. Up till now (Oct 2012) data have been analysed for the first 500 vehicles, while the remaining 200 will be possible to analyse within the near future. The initial intention was to gather data from around two months of driving for each logged device. For various reasons, not all vehicles have been successfully logged. Fig. 8 gives the length of the measurement periods for the 366 vehicles among the first 500 logged cars, for which there are more than 30 days of measurement. All figures from here on shows data from vehicles with at least 30 days of measurement. From start only 500 vehicles were to be measured but due to the somewhat low success rate in the early campaigns this has been extended to 700 vehicles. The target has been to reach 500 measured vehicles with good quality data.

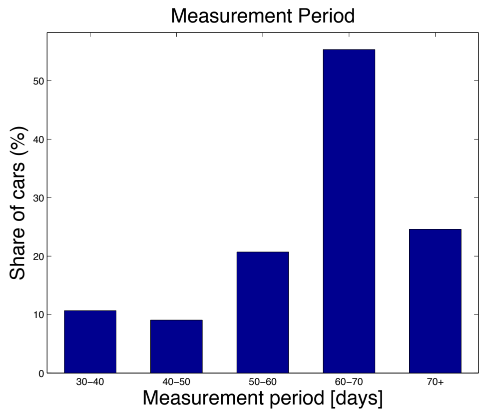


Figure 8: The length of the measurement periods for the vehicles.

Data is sometimes missing for various reasons (e.g. because of loose contact in power supply, lost satellite connection). As described above interruptions in trips shorter than 10 seconds are interpreted as a data loss and are interpolated. The GPS-equipment also need some time (often about 30 seconds) in the beginning of each trip to find satellites before it starts logging. Thus the first start-up phase for each trip is consequently missed. Detailed data on for example the speed profile for the initial start up of each trip is thus not accessible but the distance missed can be estimated as the distance (as the crow flies) between start of logging and the stop of the preceding trip. Of all the trips, 73% have a distance between start and preceding stop shorter than 100 m and for 90% it is shorter than 500 m. Long distances between end location of trip A and start location of trip B, may however not only arise from delayed logging but might be caused by losses in data. Fig. 9 illustrates how many devices that pass filtering when devices with too high percentage of trips with a distance longer than 2 km between start and preceding stop, are omitted.

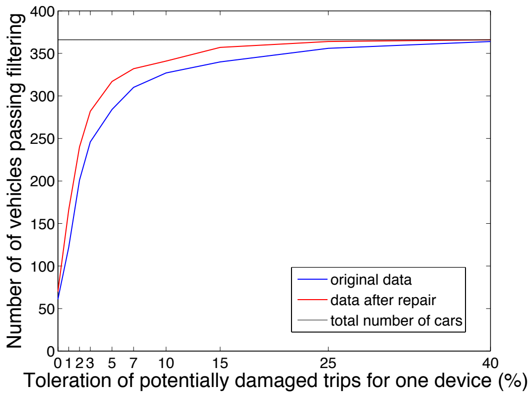
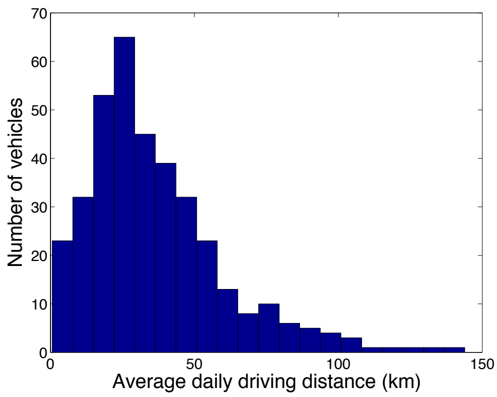


Figure 9: The number of vehicles left in data after filtering at different levels of tolerance of potentially damaged trips. With and without a simple reparation technique.

As mentioned a simple way to adjust for the missed distance is to just add it as the crow flies to the trip's distance. A bit more careful method is to use a trip advisor tool to estimate distance and travel time between the points where data is missing. If the time suggested for travel a distance corresponds to the time where data is missing one can assume that the time was used to travel the distance. This reparation technique was used together with the detection of ferry trips (for which a longer distance between start and former stop is reasonable) to form the red curve in Fig. 9. For a tolerance of 5% of the trips to have potentially lost data, these techniques enable 40% (33 out of 82) of the earlier filtered cars to be accepted. A repair of this kind can help in the case when the distance and/or time between trips are of primary interest but it will be less effective when analysing second by second vehicle speed.

Figure 10 a) shows the average daily distance driven for cars with more than 30 days of measurement. In Fig. 10 b) the stated yearly driving distance reported in the questionnaire is compared to the logged distance, scaled to one year. The scaled distances from the measurements are on average shorter than the stated yearly driving. The discrepancy might have several reasons. Faulty estimates by owners of the yearly driving, too simple scaling method (does not consider seasonal changes for example), or possibly losses in data collection. The stated yearly distance is concentrated on even numbers as 10000, 15000 km, which suggests that some owners stated rather approximate figures as their yearly driving distance. There might be a possibility to retrieve the measured yearly distance from vehicle inspections, thus giving possibility to check values against the stated ones. This does not apply to all cars though, since new cars are inspected for the first time only after three years. The measurement periods are more or less evenly distributed over the year. Thus some of the cars have a large share of holiday driving while others are without. The scaling to annual driving is therefore likely to contain some errors both in total distance and in the specific trip distribution. Data losses can, as was discussed earlier, result in underestimation of trip distance. This will to some extent become less of a problem if methods of filtering and repair are used.

a)



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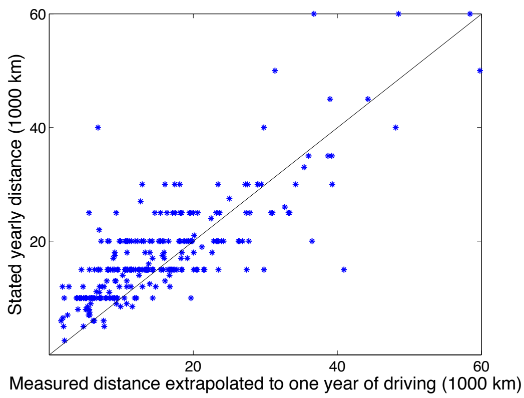


Figure 10: a) average daily distances, b) comparing stated data on yearly driving from survey with measured data, which has been extrapolated to one year.

The opportunities for charging are dependent on the stops between the trips. Figure 11 shows the average probability of each car to be parked at a certain time of the day. It can be noted that on average the cars in the fleet are parked for more than 90 % of the time at any time of the day. The most probable time of driving during the day are at around 8 am and 5 pm.

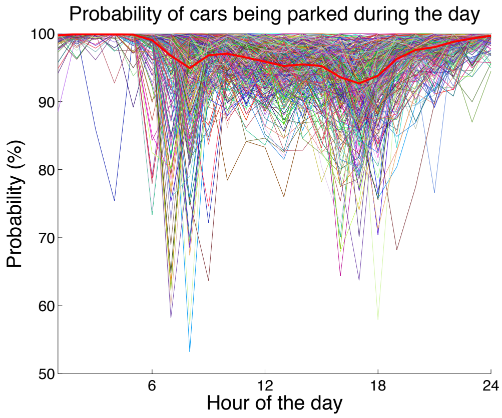


Figure 11: Probability for the logged individual cars of being parked for different hours of the day. The thicker red line denotes fleet average

Figure 12 gives the fleet average number of daily pauses longer than *T* hours, indicating the opportunities for charging when a certain length of the pauses is required for a charging to possibly occur. It can be noted that there are only 0.7 pauses per day that are 10 hours or longer. Many cars are not used every day and some drivers do not have a 10 h break over night, thus keeping the average down. If the time needed for charging is reduced to 4 hours this will roughly mean a possibility to 50 % more recharging opportunities on a fleet level. The potential occasions are again doubled if one allow for charging every half an hour.

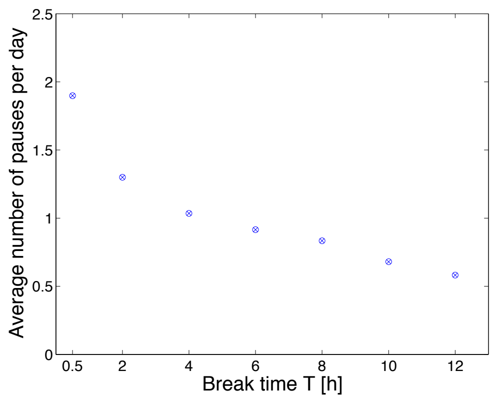


Figure 12: Fleet average number of pauses per day longer than break time *T*.

Increased knowledge on range need for individual vehicles gives important understanding of possible battery utilization and hence economic feasibility of a certain capacity [32]. Knowledge about vehicles' time available for charging also allows for analysis of other charging periods than just daily charging. Fig. 13 presents data on average daily distance (on days with driving) compared to average distance for driving periods starting after a 10, 6 or 2-hour break respectively.

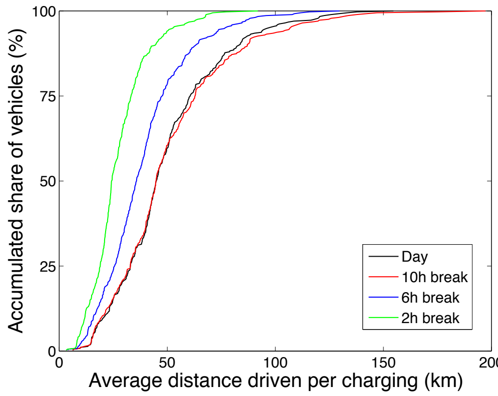


Figure 14: Fleet distribution of the average distance driven per charging, for different requirements on break time for charging to take place. For comparison average daily distance driven.

The average distances after 10 h breaks are quite similar to daily distances and thus could be used as a reasonable proxy for daily charging.[1] By adding breaks longer than 6 h, one can assume that many longer over day parkings (e.g. at workplace) are included, and by further shortening the break time required to 2 h, even some parkings in connection to for example shopping and leisure activities are included. The range-need per day or driving period varies considerably between individuals and is significantly shortened with increased possibilities of charging. Thus increased charging options leads to a decreased need for range and is thereby possibly a way to reduce vehicle price since it allows for a reduction in battery capacity.

A major shift towards electrified transport might have large impacts on the electricity supply and distribution grid. Information on power need and time of charging would then be vital, for example to foresee new need for electricity generation or to formulate strategies to spread the charging to times

[1] The average distance per driving period preceded by a 10 h break will for some cars be higher than for daily driving. This since some cars do not have a 10 h break every night and will thus sum up several days of driving in these driving periods. Other cars may instead fit two 10h-charging periods per day.

of the day with cheap power. Compared to using data from travel surveys the analysis can be done more precisely both regarding time of the day, length of pause and location of the parking/charging. Figure 15 depicts, when cars are assumed to be PHEVs, the distribution in time for pauses of different lengths and potential charging during these parkings. The need for charging is dependent on the distance travelled since last charging occasion.

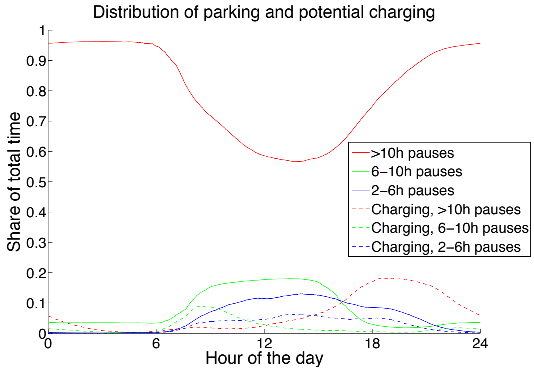


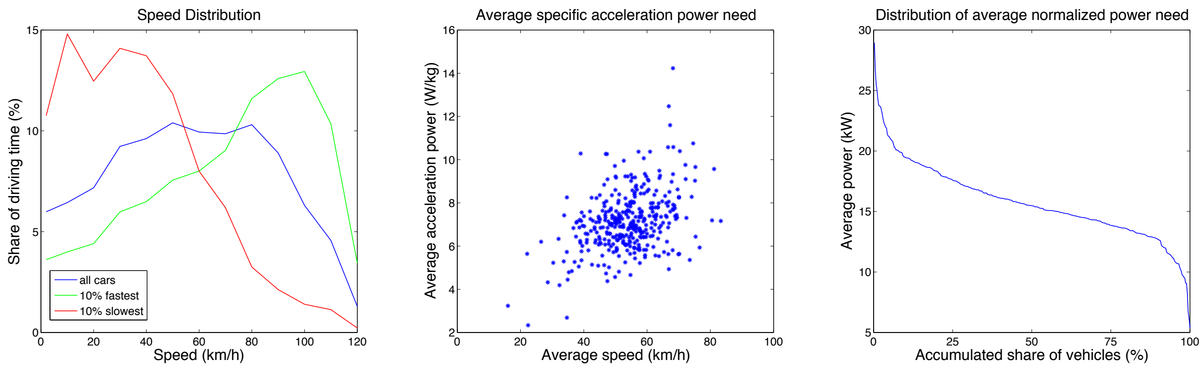
Figure 15: The distribution in time for parking of different lengths and potential charging during these pauses. Presented as shares of total measurement time for the vehicle fleet. Assumed: PHEVs with 2 kW charging immediately after parking which continue until battery is full (10 kWh) or pause ends. Energy use 0.2 kWh/km in CD mode.

With this kind of charging behaviour most of the charging will for the 10 h case be conducted between 6 and 10 pm. This is still during hours of high demand in the Swedish power grid. Increased possibilities to charge at the workplace could also lead to increased power need in hours with already high demand, assuming many of the breaks of 6 to 10 hrs length occur at the workplace. The peak is in this case located between 7 and 9 am.

Utilisation of battery capacity is not only depending on range need but also on power need when driving. Earlier research has shown that not only does real driving differ from standardised test cycles but it also differs greatly between drivers [3]. Data on actual driving on a second by second level allow for analyses of driving behaviour and the variations in power need between different movement patterns.

Figure 16 gives various aspects of the power need for the logged vehicles. The speed distribution differs significantly between the fastest and the slowest parts of the fleet, Fig. 16 a. The average specific acceleration power need depends on the average speed but varies also considerably between individual movement patterns, Fig 16 b. The distribution of the total average normalized power need is depicted in Fig. 16 c. (Note that in Figs 16 b and c, the power need is per kg and normalized to a specific car, respectively, which means that the differences are due to the movement patterns only. Power need for potential energy (height variations) and towing is omitted, though. According to the questionnaire responses about half of the cars have been equipped with a tow bar. Of these cars 20 % have been towing during the logging with a stated average towing distance of 480 km.)

Research has already been using the data gathered in the first measurement campaigns for an initial assessment of PHEVs design, viability and potential based on total cost of ownership optimization for individual movement patterns [32]. The study utilized conditions on pause lengths between trips to identify charging options



a) b) c)

Figure 16: a) Speed distribution in 10 km/h intervals when driving, given as average values for all cars and for the deciles with the highest and lowest average speed, respectively; b) The average acceleration power need per kilogram of vehicle; c) Average normalized power need. The power includes power need for overcoming rolling and air drag resistance and achieving the necessary acceleration and is for comparison normalized to properties of a midsize car.

and the accumulated trip lengths between recharging occasions to identify individually optimal battery sizes and potential share of driving on electricity.
In another study route identification routines are used to find regularities in the car movement patterns to be able to predict where it is heading. By combining route identification with optimizing algorithms for energy management, the fuel use in a PHEV may be considerably reduced [4].

4 Conclusion

The described Swedish car movement data project provides a high quality data set with detailed information on multi-day movement patterns of a representative share of privately driven cars in Sweden. Such data have potential use in many areas but is especially valuable for various developments and assessments in connection to vehicle electrification.

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