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GPS measurement of Swedish car movements for assessment of possible electrification

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Abstract

To enhance the transition to electrified vehicles, such as PHEVs, the use patterns of cars need to be well understood and thus information about individual vehicle's movements over longer time periods is needed. This is of major importance for instance for optimal powertrain and battery design, estimation of consumer viability and potential for PHEVs and for assessment of policies for shifting 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 (2.5 Hz) were: time, position, velocity, and number and id of used satellites. The measurements started in June 2010 and ended in September 2012. The target has been to accomplish good quality measurements of at least 30 days for about 500 representative vehicles. The paper includes a description of the project, an analysis of its representativeness and some car movement statistics for the full results.

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

1 Introduction

Increased electrification of cars has lately been frequently suggested as a potential solution to several important problems related to car transport such as greenhouse gas emissions, local emissions and fuel security. 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 the transport sector from fuel to electricity [1], [2], [3]. Comprehensive data sets are also needed in order to design and optimize the powertrain by vehicle simulations [4].

Publicly available data of high quality on individual car movement patterns is today unfortunately not very common. Measurements of individual cars in everyday traffic with for example GPS equipment have been conducted but are often done for a specific purpose, with low logging frequency, or are limited to short measurement periods. For a further discussion on other GPS-datasets, see [5].

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 measurements are now finished. We will here give a description of the project and an overview and analysis of the results and their representativeness. Some preliminary results of the project have been presented earlier [5]. This presentation is therefore an extension and update of this earlier paper and contains some common material. A description of the project is also available in a project report [6].

2 Method

2.1 Selection of vehicles

In nine campaigns a total of 770 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 inquiry 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 [7, 8]. They are restricted to a maximum of 8 passengers apart from the driver, and a maximum weight of 3.5 tons. Vehicles, which, according to the vehicle register, are used in commercial traffic, such as taxicabs, were not included in the excerpt due to our focus on privately driven cars. The excerpt was also restricted to cars of model year 2002 and younger. Electric vehicles, of which only a few exist though, were excluded, due to their range limitation and therefore possible specific movement pattern. There are also on-going other projects dedicated to various measurements 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

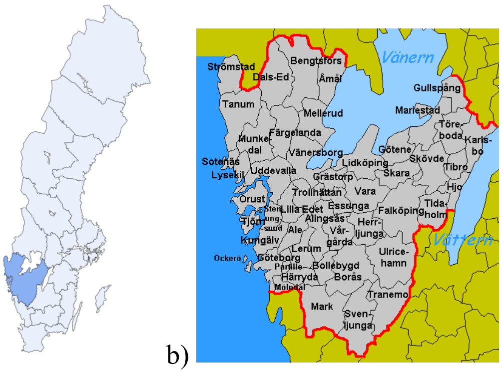
Cars owned by companies or public institutions may be used in specific ways dependent on the situation specific for each vehicle, for instance, to transport personnel between patients in the eldercare. Use patterns of these cars are less representative and can sometimes be reasonably gathered by other 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 information on which cars are 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 [9]. 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 the company cars were identified and extracted by addressing the inquiry letter to the driver of the specified car and asking if it was a company car. When so, it was 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 was 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 in order 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 were 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 was set to March 1, 2002 and younger. In the last campaign only cars registered after February 1, 2004 were used. This selection of younger cars constituted roughly 45% of the total car fleet and 60% of the total distance driven [10]. 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.

Table 2: Data for the selected region at the end of 2010.

Parameter	Selected region	Sweden	Region/ Sweden
Inhabitants (millions)	1.655	9.416	0.176
Land area (1000 km²)	25 424	449 964	0.0565
Inhabitants/area (km²)	65	21	3.1
Registered cars in use (millions)	0.750	4.335	0.173
Cars/1000 inhabitants	453	460	0.984
Average driving distance in 2008 (km)	13 610	13 390	1.016



a) b)

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 were 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. The region's population density of around 65 inhabitants/km^2 is three times the average for Sweden, but reasonable representative for the southern parts of Sweden where most inhabitants live.

Several cars have their owners not living within the region or belongs to companies situated in another area according to the registered postal address. This can concern cars with owner in a completely different part of the country such as Stockholm. It can also be owners with addresses belonging to a postal office close to, but outside the border. The selection was further restricted to owners of the cars with their addresses belonging to postal offices within the region. The effect of this further refinement was that about 0.5‰ of the cars belonging to natural persons (≈ 340 000) were excluded, and 1.5% of the cars registered for juridical persons (≈ 43 000) were not included in the final selection.

The random selection was stratified into 14 groups along five parameters, which are known or thought to statistically influence the car movement patterns, Table 3. The cars were 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. In the weighting 70% and 97% of the juridical and private cars, respectively, are assumed to be privately driven.

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 [11]. 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.

The cars were 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 was assumed that the movement pattern in this larger town area possibly can differ considerably from the rest in various aspects.

Since younger cars are used more intensively than older ones [11], the cars were stratified along age in two groups: older and younger than 40 months, respectively.

Table 3: The applied stratification of the vehicle selection into 14 groups.

Fleet	Stratification parameter					Strata designation	Statistical share[g]
	Ownership	***Geographic area[a]***	***Fuel***	***Car age[b]***	***Kerb weight[c]***		
Selected fleet	Natural person[d]	Gothenburg, Mölndal, Partille	All other fuels[f] (AOF)	Young	Heavy	GB7T	1.31
					Light	GB7L	4.51
				Old	Heavy	GB6T	5.86
					Light	GB6L	10.63
			Diesel	Young		GD7	3.12
				Old		GD6	1.95
		Remaining region	AOF	Young	Heavy	ÖB6T	3.25
					Light	ÖB6L	7.97
				Old	Heavy	ÖB7T	14.97
					Light	ÖB7L	21.65
			Diesel	Young		ÖD7	8.41
				Old		ÖD6	7.42
	Juridical person[d]		AOF			JB	4.72
			Diesel			JD	4.24

[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] 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.
[g] Mid-project point of time value for privately driven cars.

For each randomly picked vehicle from the excerpt, a 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 questionnaire that was sent to all participants and with a response frequency of over 93 %, gives some data on the logged cars, their drivers and households.

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. By avoiding a more advanced connection through the CAN bus the risk of interference 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.

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 allowed for storing data for a longer period without contact with the mobile network. This feature has enabled also movement patterns for any abroad driving to be gathered. The gprs communication was 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 [12].
To each measurement device was connected a vehicle in the form of the car register number and to each logging a road classification identity, which gives the speed limit and categorize the road into urban, highway or other. An algorithm has been developed for connecting a data point (the horizontal position) to a specific spot on a road to be able to get the road classification identity.

Table 4: Movement statistics per trip in the analysis database and current availability at the web interface.

Parameter	Web
Number of trips	x
Start time for first trip	x
Stop time for last trip	x
Total duration of the trips	x
Total travel distance	x
Average trip distance	x
Maximum trip distance	x
Trip distance histogram	x
Maximum speed	x
Average speed	x
Average of speed squared	
Average of speed cubed	
Speed histogram	x
Average of positive acceleration • speed	
Average of negative acceleration • speed	
Average number of trips per day[a]	
Maximum number of trips per day[a]	
Pause time histogram	x
Travel timepoints-of-the-day histogram	
Travel distance per day histogram[a]	
Number of trips per day histogram[a]	
Acceleration vs Speed diagram	

[a] Applied definitions: *Day*: The break point of time between days is 03.00 in the morning. Trips starting before this point of time is accounted to the day before; *Time*: The start and stop times for a trip is the time for start and stop of the logging, whether the car moves or not. This definition is used also in the estimates of the averages.

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 was 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 times and locations for trip start/stop, travelled distance, averages of speed, of speed squared, and of speed cubed, trip duration, number of interpolated data gaps and values. Table 4 gives an account of the available trip statistics in the analysis database.
The third level holds statistical data for each device/vehicle such as total distance travelled during the measurement period, points of time for first/last measurement, average speed for all driving, total number of trips etc. Table 5 shows the available vehicle statistics in the analysis database.

Table 5: Movement statistics per vehicle in the analysis database and current availability at the web interface.

Parameter	Web
Start time	x
Stop time	x
Trip duration	x
Pause time before trip	x
Pause time after trip	x
Start horizontal position	
Stop horizontal position	
Travel distance	x
Maximum speed	
Average speed	x
Average of speed squared	
Average of speed cubed	
Final speed	x

The analysis database also holds some data quality and analysis statistics concerning, for instance, entries discarded and interpolated or corrected values.

Most of the data in the analysis database is available via a webpage, see Tables 4 and 5. The data is available for research concerning energy and environment, safety, and traffic planning and can be accessed at the TSS website [12]. Due to the privacy character of some of the data, the availability is classified according to type.

3 Resulting data from the measurements

3.1 Derived data sets

We will here present the logging in terms of the involved cars, their household and spatial distribution, report the outcome of the measurement and its quality, and give some exemplary results concerning the car movements. Altogether around 770 cars have had GPS equipment sent to them for measurement of their movements. Some of these have not installed the equipment or the equipment has not registered any data. 714 cars have delivered data. (These cars with data are directly available in for instance the analysis database.) Of these vehicles 528 cars have had their movements logged for 30 days or more, that is, the difference between first and last gathered data is at least 30 days. (Still there can be missing data within this logging period.) (These 528 cars can relatively easily be extracted from the analysis database.) In the continuation the data for the 714 cars are called *Data All Cars* and for the 528 vehicles *Data Cars 30d+*. The 697 answers to the questionnaire are here designated *Questionnaire.*

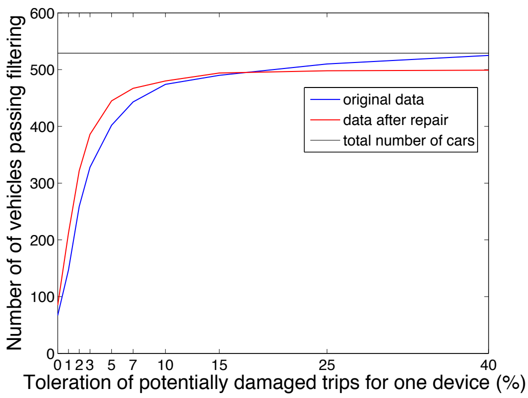


Figure 2: The number of vehicles left in data after filtering at different levels of tolerance of potentially damaged trips. With and without a simple reparation technique. Source: *Data Cars 30d+*.

To present some of the results a dataset has been derived, for which apparent missing data (non-continuity in position) has been interpolated and time periods for which possibly missing data have not been possible to identify have been excluded. This dataset consists of 445 vehicles with data for 30 days or more. It is here called *Data Cars Corr 30d+* and is derived as follows. (This last dataset is not available in the analysis database, but requires some data manipulation.)

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 the start position of logging and the stop location of the previous trip. Of all the trips, 73% have a distance between start and previous stop shorter than 100 m and for 90% it is shorter than 500 m. Long distances between stop 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. Figure 2 illustrates how many devices pass filtering when devices with too high percentage of trips with a distance longer than 2 km between start and previous stop, are omitted.

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 roughly 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 detection of ferry trips (for which a longer distance between start and previous stop is reasonable) to form the red curve in Fig. 2. For a tolerance of 5% of the trips to have potentially lost data, this technique enables about 35% of the earlier filtered cars to be accepted to reach a total after filtering of 445 cars. A repair of this kind can help in cases 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.

3.2 Participating cars and households

The recruitment procedure did not lead to any significant misrepresentation concerning the properties of the cars. Table 4 shows that the 714 cars with data in average are fairly representative for the vehicles they are supposed to represent as determined in the excerpt from the vehicle register.

The outcome concerning the distribution of the cars over the different strata is shown in Table 5. It agrees reasonably with the desired distribution.

Table 4: Average values for selected parameters of vehicles in dataset *Data All Cars* in comparison to the vehicles in the vehicle register.

Parameter	Average for cars with data	Average[a] from vehicle register
Model year	2006.37	2006.12
Maxi. engine power (kW)	98.2	99.5
Cylinder volume (cm^3)	1819	1812
Kerb weight (kg)	1456	1457
Fuel use (litre/100km)	7.22	7.26
CO_2 emission (g CO_2/km)	176	177

[a] Weighted average between juridical and private cars in the same proportion as in the excerpt from the vehicle register further discussed in Section 2.1.

Table 5: Distribution of the logged vehicle over the different strata. Source: *Data All Cars*.

Strata	Outcome (*Data All*) (Number)	Outcome (*Data All*) (%)	Desired distribution[a] (Number)	Desired distribution[a] (%)
GB7T	10	1.40	9.3	1.31
GB7L	33	4.62	32.2	4.51
GB6T	41	5.74	41.8	5.86
GB6L	71	9.94	75.9	10.63
GD7	29	4.06	22.3	3.12
GD6	15	2.10	14.0	1.95
ÖB7T	26	3.64	23.2	3.25
ÖB7L	59	8.26	56.9	7.97
ÖB6T	110	15.41	106.9	14.97
ÖB6L	147	20.59	154.6	21.65
ÖD7	62	8.68	60.0	8.41
ÖD6	52	7.28	53.0	7.42
JD	29	4.06	33.7	4.72
JB	27	3.78	30.2	4.24
Unknown	3	0.42	0	0
Sum	714	100	714	100

[a] From Table 3.

Table 6: Distribution of cars over the different municipalities in the region. Source: *Data All Cars* and The Swedish motor-vehicle register.

Region	Distribution over subregions (*Data All Cars*)	Desired distr. over subregions[a]
Gothenburg region	220	227
2 larger cities	80	88
16 smaller cities	290	260
29 smallest municipalities	124	138
Unknown	3	0
ALL	714	714

[a] Values at mid-project point of time for privately driven cars.

There is a major over-representation for newer diesel cars in the Gothenburg area as well as a major under-representation of juridical cars, especially diesel cars. Most of the juridical cars are situated in the Gothenburg area, are relatively new cars and diesels. These misrepresentations may therefore concern close categories of customers, why they to some extent may compensate for each other.

The geographical representation by the single municipality varies especially for smaller municipalities, in which the desired numbers of cars are small. However when aggregated into 4 groups of municipalities of different sizes (the three municipalities in the Gothenburg area are aggregated in a separate group), the various sizes are well represented, see Table 6. There is a small overrepresentation of smaller cities, while the other groups have fewer cars than desired.

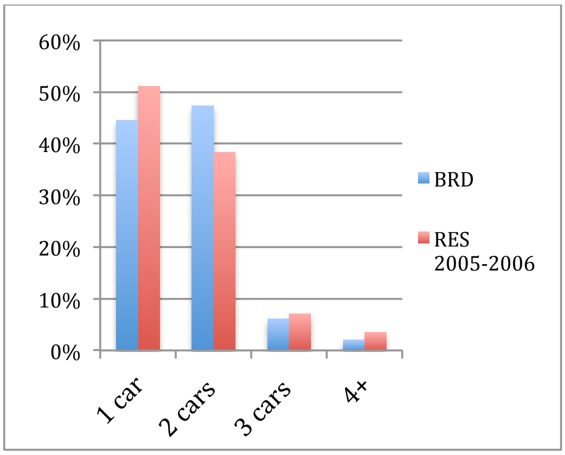
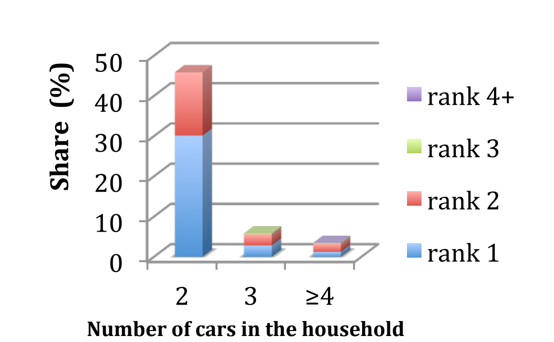


Figure 3: Share of the cars belonging to households with different number of cars in this study (BRD). For comparison the corresponding figures for whole of Sweden given in The Swedish Travel Survey (RES 2005-2006). Source: *Questionnaire* and [13].

A majority of the cars belongs to households with more than one car, see Fig 3. Compared to the Swedish households in general there is a slight overrepresentation of households with more than one car. This is probably (partly) due to the fact that this study is directed towards newer cars, which predominantly may belong to wealthier households with several cars. The comparably low age of “our car” may explain why it also has somewhat longer yearly driven distance than the other car(s) in the household, see Fig 4a. In average it is not perceived bigger than the other cars though, see Fig 4b.

63% of the selected cars were used for commuting, although not necessarily during the measurement period, with an estimated average commuting (one-way) distance of 29 km, see Fig 5.

a)



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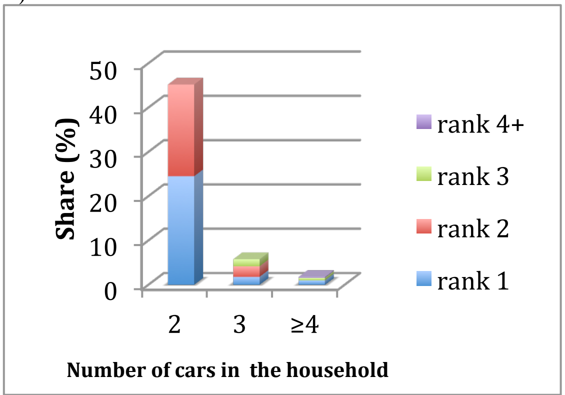

Figure 4: For logged vehicles belonging to a household with more than one car, share of stated rank among the household's cars of a) yearly driven distance (longest = 1) and b) size (largest = 1), respectively. Source: *Questionnaire.*

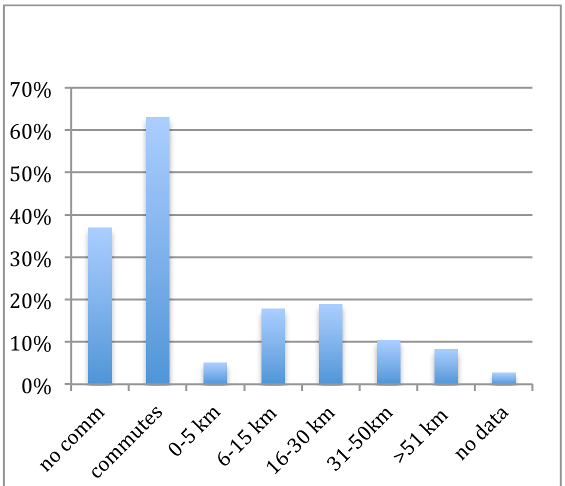

Figure 5: Stated commuting for the vehicles (not necessarily during the logging period). Source: *Questionnaire.*

3.3 Logged driving

Table 7 gives some basic statistics for the logging. The total distance logged is over 1.3 million kilometres corresponding to almost 3 years of driving data. Any division of travel data into "trips" is not clear cut. The procedure used here, if anything, "overestimate" the number of trips and should be treated with caution. (The procedure was discussed in Section 2.3.)

Table 7: Basic statistics for the logged car movements.

Statistics	*Data All Cars*	*Data Cars 30d+*	*Data Cars Corr 30d+*
Number of cars with data	714	528	445
Total distance (km)	1 314 002	1 207 141	1 174 298
Total travel time (hours)	24 801	22 776	n. a.
Average distance (km)	1 840	2 286	2 639
Average speed (km/h)	53	53	n. a.
Number of trips[a]	134 425	124 458	113 293
Average number of trips[a]	188	236	255
Average trip length[a] (km)	9.8	9.6	10.4
Av. number of trips per day[a]	3.8	3.7	4.4

[a] Trip statistics are sensitive to the division of the logging data of the car movements into trips.

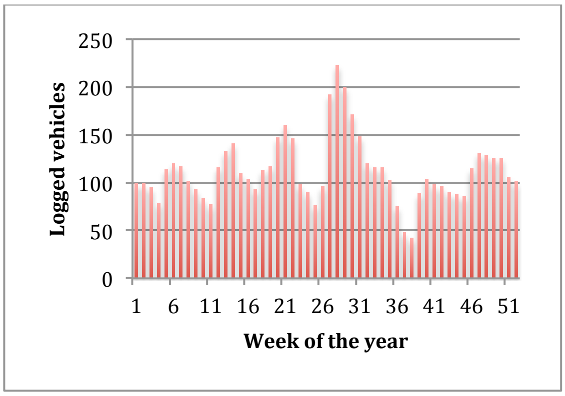

Figure 6: Distribution in time of the logging periods for the vehicles. Source: *Data All Cars*.

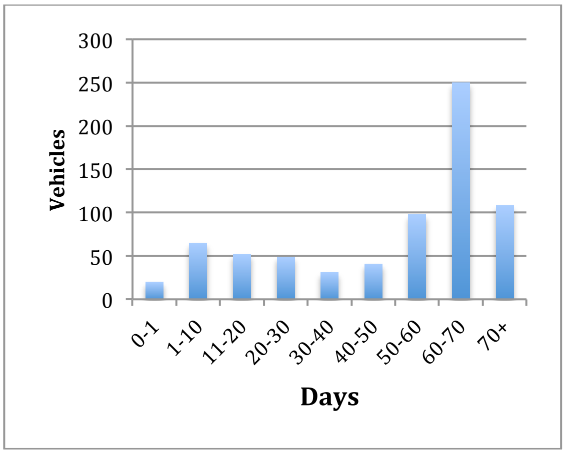

Figure 7: The length of the measurement periods for the vehicles. Source: *Data All Cars*.

The intention has been to distribute the logging over the year, although simultaneously a continuity of the campaigns and the availability of equipment have been taken into account. Figure 6 gives the distribution of the performed loggings over the year. We can see that there is a somewhat larger concentration of loggings in the summertime during the Swedish vacation period in July. Several campaigns started just before the vacation period, because otherwise it had to be delayed to after the summer.

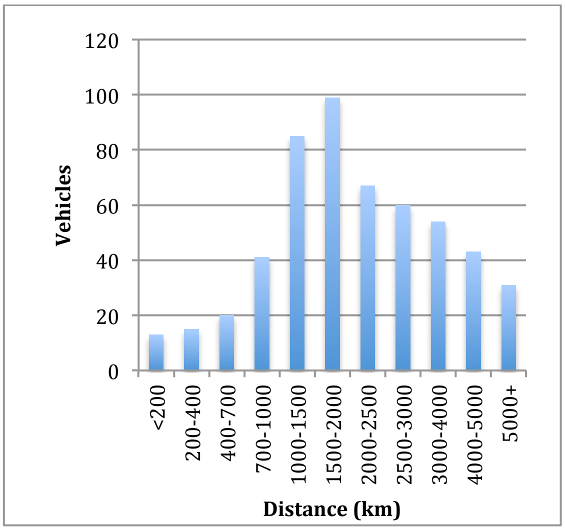

Figure 8: Distribution of the logged driving distance. Source: *Data Cars 30d+*.

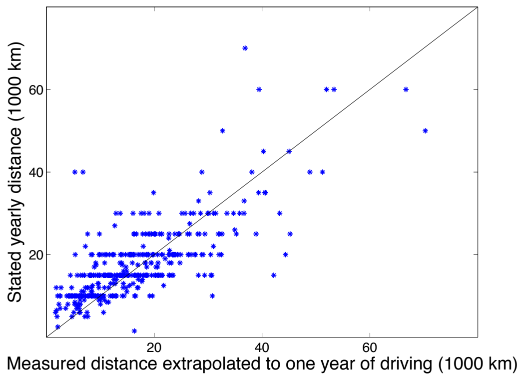

Figure 9: Stated yearly driving distance (Source: *Questionnaire*) compared to logged data extrapolated to one year (Source: *Data Cars Corr 30d+*).

The length of the actual measurement period, shown in Fig 7, is for some vehicle much shorter than intended due to malfunction of the equipment. 528 vehicles have loggings for more than 30 days (= *Data Cars 30d+*) and over 450 for more than 50 days. A large majority of the vehicles logged for more than 30 days has logged distances of over one thousand kilometres, see Fig 8.

Figure 9 shows the extrapolated logged distance in comparison to the yearly driving of the vehicles as stated by the owner/driver in the questionnaire.

The variation in the fit between individual vehicles is large. This discrepancy might have several reasons. The stated yearly distance is concentrated on even numbers, which suggests that some owners stated rather approximate figures as their yearly driving distance. The measured period may not be representative for the annual driving. The scaling to annual driving is therefore likely to contain some errors both in total distance and in the specific trip distribution. 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.

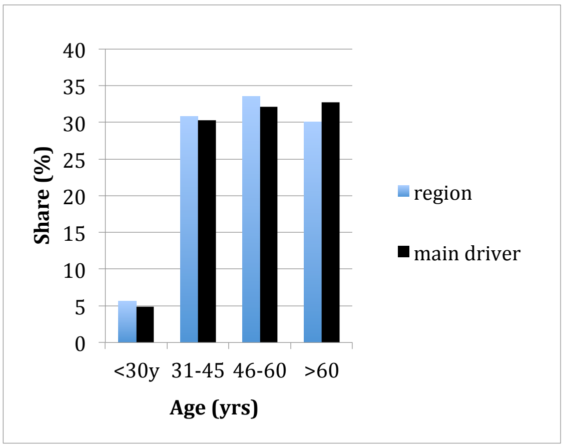

Figure 10: Stated age of main driver of logged cars and age of car owners in the region. Source: *Questionnaire.*

The age of the main driver of the cars during the loggings is somewhat higher than expected from representative car owner data as shown in Fig 10. Older people may thus be more willing than younger ones to participate in this type of investigations. No compensation for this effect was done in the recruitment, as it was not part of any predetermined strata.

3.4 The car movements

Here is presented some statistics for distances driven, pauses and power involved in the driving. Increased knowledge on range need for individual vehicles gives important understanding of possible battery utilization and hence economic feasibility of a certain capacity [14].

Figure 11 shows the average daily distance driven. As also indicated indirectly in Fig 9 the daily driving varies a lot between individual cars.

Figure 12 depicts the distribution of the number and length of the trips. (Trips defined according the procedure described in Section 2.3.) While the number of trips is dominated by short trips, the most common driving belongs to a trip between 30 and 50 kilometres. Not much more than 10% of the driven distance belongs to trips longer than 100 kilometres.

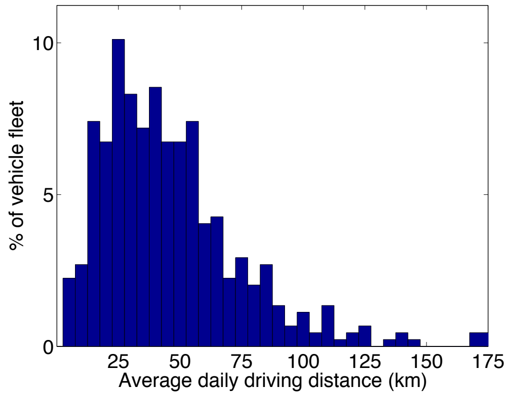

Figure 11: Average daily distances driven during the measurement period. Source: *Data Cars Corr 30d+*.

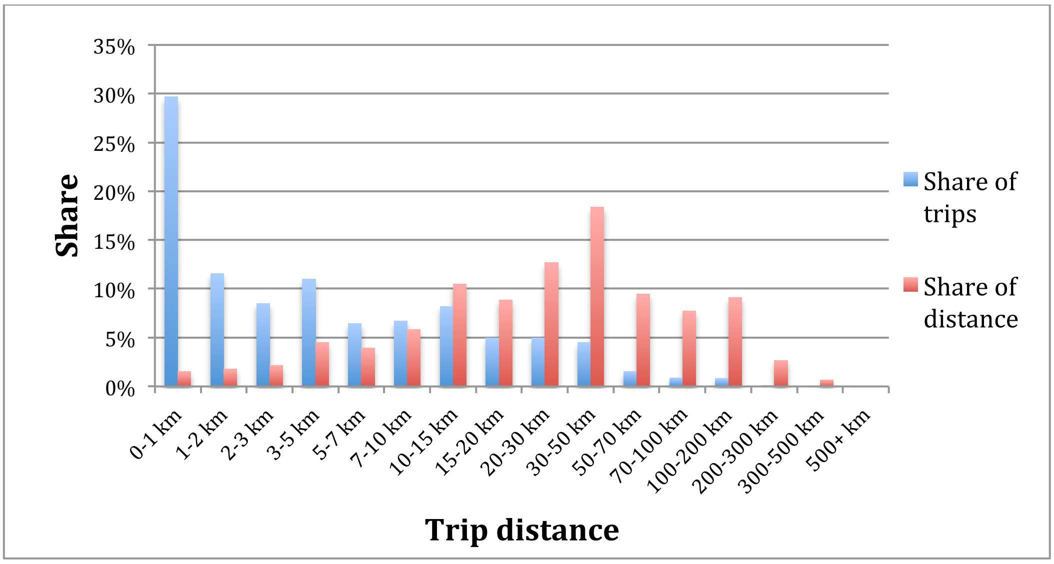

Figure 12: Distribution of trip distances. Source: *Data Cars 30d+*.

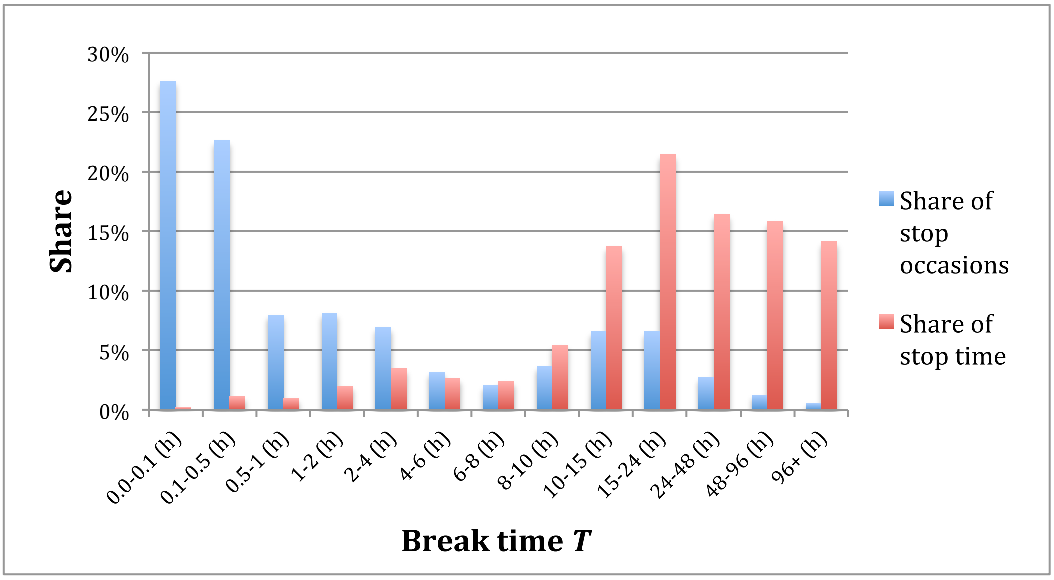

Figure 13: Distribution of the length of stops. Source: *Data Cars 30d+*.

A similar relation holds for the pauses between trips, see Fig 13. The number of pauses are dominated by short breaks, but at any time a random car not driving has probably stood there for a long time. The time between trips are totally dominated by longer pauses; almost 90% of the time a car is parked belong to a pause longer than 8 hours.

The opportunities for charging are dependent on the stops between the trips. Figure 14 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 93 % of the time at any time of the day. The most probable time of driving during the day is at around 8 am and 5 pm.

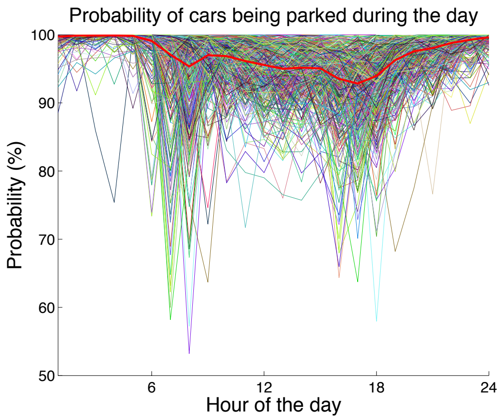

Figure 14: Probability for the logged individual cars of being parked for different hours of the day. The thicker red line denotes fleet average. Source: *Data Cars 30d+*.

Figure 15 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.

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 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 16 depicts the distribution in time for pauses of different lengths and as an illustration potential charging during these parking occasions, when the cars are assumed to be PHEVs,. The calculated need for charging is dependent on the distance travelled since last charging occasion.

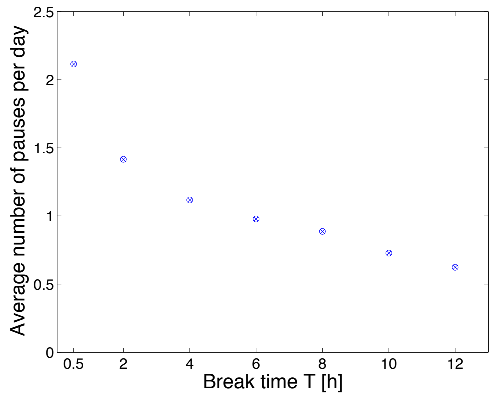

Figure 15: Fleet average number of pauses per day longer than break time *T*. Source: *Data Cars Corr 30d+*.

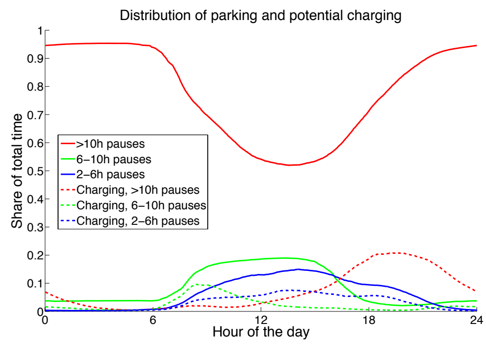

Figure 16: The distribution in time for parking of different lengths and as illustration possible charging during these pauses. Presented as shares of total measurement time for the vehicle fleet. Assumed charging: PHEVs with 2 kW charging immediately after parking which continues until battery is full (10 kWh) or pause ends. Energy use 0.2 kWh/km in CD mode. Source: *Data Cars Corr 30d+*.

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.

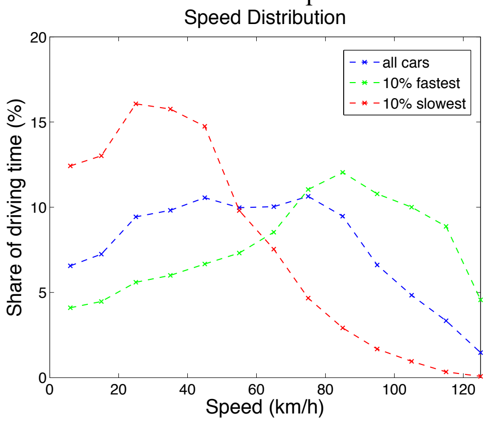

Figure 17: Speed distribution in 10 km/h intervals when driving, given as average values for all cars and for the deciles with the highest and lowest average speed, respectively. (Source: *Data Cars Corr 30d+*)

The speed distribution differs significantly between the fastest and the slowest shares of the fleet, Fig 17. The slowest vehicles seldom drive faster than 70 km/h, while the fastest decile has a high share of the driving on highways at speeds in the range of 80-110 km/h.

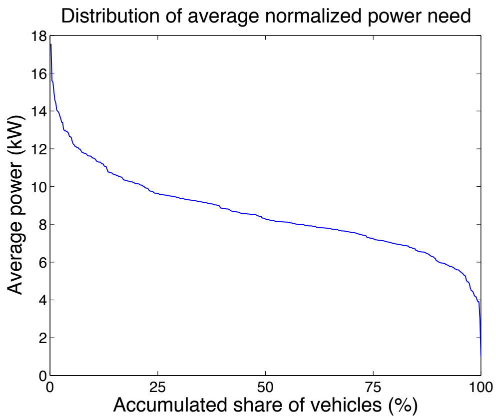

Figure 18: Average normalized power need. The power includes power need for overcoming rolling and air drag resistance and achieving the necessary acceleration and is for comparison normalized to properties of a midsize car (mass M = 1500 kg, air resistance C_d *A = 0.70 m^2, and rolling resistance c_r = 0.01.) (Source: *Data Cars Corr 30d+*)

The distribution of the total average normalized power need is depicted in Fig 18. Note that here the power need is given per vehicle mass unit and normalized to a specified car, which means that the differences between cars 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 22 % have been towing during the logging with a stated average towing distance of 470 km.)

Figure 19 gives the average normalized energy need at the wheels per distance driven for the different vehicles corresponding to the power need of Fig 18. We can note that the comments made to Fig 18 are applicable also to this figure. The normalized specific energy need (as defined here) is in average around 1.5 kWh per 10 km for Swedish driving, while the ultimate losses in average are below 1 kWh/10 km. The variation in energy need gives an indication in the actual range for an electric vehicle due to this factor alone. (Other factors of importance can be the auxiliary energy need and energy conversion efficiency within the vehicle [15]. Also energy recovery is of larger importance for electrified vehicles than for conventional ones [16].)

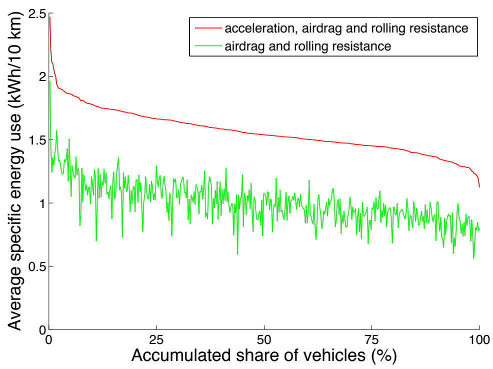

Figure 19: Vehicle average specific energy need at the wheel when driving ≥ 2 km/h. The need is estimated as the sum of energy needs for overcoming rolling and air resistance and energy for achieving the positive acceleration. For comparison of movement patterns, the energy need is for all the vehicles normalized to the properties of an assumed midsize car (mass M = 1500 kg, air resistance C_d *A = 0.70 m^2, and rolling c_r = 0.01). (Source: *Data Cars Corr 30d+*)

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 [14, 17]. 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 Conclusions

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 research, developments and assessments in connection to vehicle electrification.

5 Acknowledgments

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