EVS27
Barcelona, Spain, November 17-20, 2013

A GPS-based Research on Driving Range and Patterns of Private Passenger Vehicle in Beijing

Hewu WANG[1], Lvwei WU[1], Cong HOU[1], Minggao OUYANG[1]
[1]Author 1 State Key Laboratory of Automotive Safety and Energy, Tsinghua University, Beijing, P.R. China, wulvwei@163.com

Abstract

The driving range and patterns of private passenger vehicle in Beijing are discussed in this paper, basing on the advanced GPS travel survey. From the sample of 106 cars, 1652 days and 3920 trips collected in the second half of 2012 and early 2013, the distribution of daily driving range, time and frequency are calculated out. The results show that in Beijing, the daily vehicle kilometers travelled of the year 2012-2013 is 33.5km, and the driving time is 1.6h per day. Besides, there are 2.4 driving trips per day on average, when the average range is 14.1km per trip. The battery electric vehicle (BEV) may cover 80% daily travel with the all-electric range (AER) set as 60km. If the BEV is charged reasonably, its applicability and endurance will be better.

Keywords: GPS, private passenger vehicle, driving patterns, distribution of range

1 Introduction

The driving patterns of private passenger vehicle are very important not only to the urban traffic management, but also to the electric vehicle (EV) design. Based on the National Household Travel Survey (NHTS), GM sets all-electric range (AER) for Range Extended Electric Vehicle (REEV) [1]. A survey on driving patterns of 12 plug-in hybrid electric vehicles （PHEV） in California indicates that a lower battery capacity and a blending control system are more conducive to early market expansion [2]. In the vehicle energy-consumption and emission evaluation model that HAO *et al* established (2011), vehicle kilometers travelled (VKT) is a vital block Accordingly, VKT and driving patterns attach great importance to setting component parameters and evaluating energy-saving effect of electric vehicle (EV) [3,4].

Researches on driving range and driving patterns oversea have been matured. NHTS (2009) reports in a one-year driving survey that the daily VKT is about 52km in the U.S.[5]. A GPS-based research in Atlanta indicates that an overwhelming majority of daily VKT is less than 80km [6]. Another research (2010) points out that about 40% daily VKT of private commuter cars is less than 20km in Britain, Ireland and the U.S.[7]. However, similar researches in China, particularly based on GPS, are normally involved in the comprehensive traffic survey. In Beijing (2010), there are 2.58 driving trips per day in weekday, which is higher than 2.11 trips on holiday. The VKT of the year is 21161km [8]. The VKT in Shanghai (2008) is 39km, and single trip, of which range is less than 10km, covers 43% of the trip [9].

In China, researches on driving range and patterns are not common. Most of them are based on questionnaire and other "memory data", which cannot deal with detail features well. We analyze the driving range and patterns of private passenger vehicle in Beijing based on GPS travel survey, in order to obtain the basic patterns of daily driving as well as provide support for optimizing the design of EV.

2 Methods

2.1 Platform estabishment

GPS-based researches on driving patterns could acquire faithful data on driving track and movement, avoiding the indeterminacy and eliminating potential misreporting and underreporting Compared with traditional approaches (e.g., driving diary and telephone interview), GPS-based research is more objective, accurate, and informative [10].

We establish a GPS data collection platform to support the present research:

(1) Data-collecting flow

For normalization and reproducibility, data should be collected as follows: First, recruit and record voluntary vehicles according to sampling principle; Second, sign data collection agreement and install devices for data recording; Third, reclaim the device as scheduled and validate the data; Fourth, input the valid data into the database based on its protocols.

(2) Devices

The selected GPS device should be: First, small, light, and easy to carry with vehicles; Second, installation and operation of the devices do not affect the use of the vehicle; Third, a good signal reception and a fast start and positioning; Fourth, a long battery life and big data storages; Fifth, high frequency and precision in data logging

Considering the requirements above, A GPS device called COLUMBUS V990 is adopted to collect the data. COLUMBUS V990 has a auto ON/OFF function when car-using. It receives and logs once a second if the signal is good. The data will be saved when the engine stops. Key parameters of V990 are listed in table 1.

Table1: Main specification of V990

name	specification
dimension	43mm×74mm×9.9mm（L×W×H）
weight	55g
frequency	1575.42Mhz (L1, C/A code)
sensitivity	Better than -165dBm
Acquisition time	Hot start: 1 second, Cold start: 35second (The test environment shall be a place in open sky)
Minimal data resolution	1/10000 minute (Latitude, Longitude), 0.1km/h (velocity)
Protocol output	NMEA Ver 3.01
Update frequency	1Hz (default)
Storage capacity	4G
dimension	43mm×74mm×9.9mm（L×W×H）

2.2 Data processing

On the basis of Theory on Traffic Planning [11], we define the driving trip as a process that a vehicle drives from origin to destination purposely. The present research only focuses on the result of OD (short for Origin to Destination). The 'OD' information of driving trip will be read and calculated out from the firsthand database where valid data are input through the platform. Then sub-database of driving trip is established with each piece of trip information as basic cell, thus obtaining driving range and patterns.

During massive data collection with GPS, unreasonable might occur in the area where the environment is not satisfied, so that primary data should be screened and filtered first. Then OD information of each trip is picked out by data cutting and merging. Finally, a number of information is acquired, i.e., volunteers' ID, origin moment, destination moment, latitude and longitude of driving origin, latitude and longitude of driving destination, and driving range. The data processing flow is shown in figure 1, with some key details as follow:

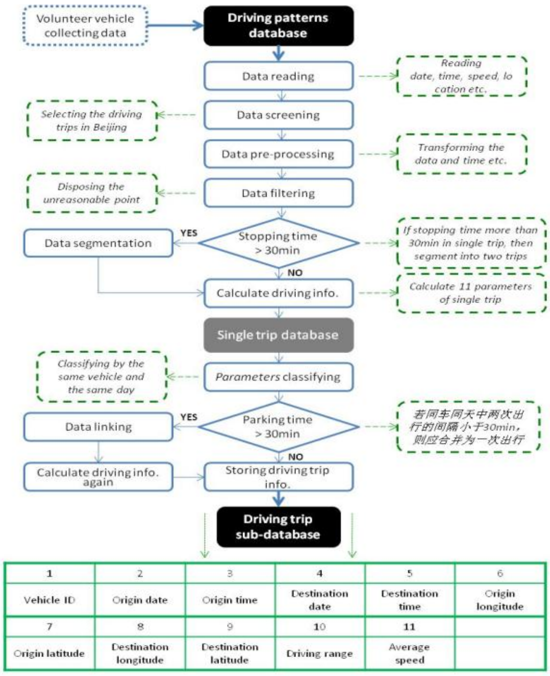

Figure1: The data processing flow of establishing the OD sub-database

1) Setting some threshold value to filter the unreasonable data: speed $\leq$ 180km/h, acceleration absolute value $\leq$ 8m/s^2, absolute rate of acceleration change $\leq$ 10m/s^3.

2) If the stopping time (speed=0) is more than 30min in a single trip, the trip will be segment into two trips. Besides, if the parking time between two trips is less than 30min, the two trips will be linked up as a single trip.

3) The GPS device cost about 0.5min from turning on to recording data. Because of the low-speed when vehicle starting to move, the unrecorded driving range can be ignored.

3 Results

3.1 Characteristics of sample

We adopt a random sample in the present research. In order to make the results representative and reliability, main characteristics of sample should be as follow:

1) The sample should be consisted of driving trips in weekday and weekend, excluding trips in May day, National day holiday and other long holidays (more than three days).

2) The origin and destination of driving trip should be both in Beijing and cover the main districts and road type.

3) The sample is expected to be recruited from companies in the area around destination and the origin of the sample should be decentralized as much as possible.

4) The sample should have a good driving record and is willing to work for data collection. Driving behavior of the sample should not be affected and changed by the research.

5) The sample vehicles should be used for private or household purposes, such as commuting, shopping, visiting friends, and entertainment.

Based on the requirement above, the sample of 1652 driving days (461 days are weekends, accounting for 27.9%) and 3920 trips are inputted into database. There are two periods for the sample collection, a short one (2w~4w) and a medium/long one (4w~8w). All the samples are collected in the main urban and suburb districts of Beijing, namely: West District, East District, Haidian District, Chaoyang District, and Fengtai District. Internet companies, technology companies, universities, scientific research institutions and freelancers are also involved in the collection. Generally, the samples have a good education background and a decent income. With Changan avenue as the North-South dividing line and axle wire as the East-West dividing line, We divide Beijing into four areas: northwest, northeast, southeast and southwest area. All the OD in these four areas are shown in table 2. Northwest and northeast Beijing has the most OD, especially in Zhongguancun area and pan-Wangjing area. This distribution is in accordance with the results of the third comprehensive traffic survey in Beijing [12]. The survey shows that traffic flow is transferred from East-West direction to North-South direction, with Zhongguancun area (middle area of Haidian district) and pan-Wangjing area (north area of Chaoyang district) as two major centres. Contacts in north Beijing and middle Beijing are more than that in the south.

Table2: The distribution of travel OD in Beijing

	northwest	northeast	southeast	southwest
Origin	30.5%	32.6%	16.9%	20.0%
Destination	29.5%	33.0%	16.4%	21.1%
Total (O&D)	30.0%	32.8%	16.7%	20.6%
	Inside 2nd ring road	Inside 3rd ring road	Inside 4th ring road	Inside 5th ring road
Origin	11.5%	30.1%	49.3%	73.1%
Destination	10.8%	28.9%	49.7%	74.5%
Total (O&D)	11.2%	29.5%	49.5%	73.8%

As shown in figure 2, distribution of the sample in ring road accords to the trend of driving trips on the whole. Consequently, the sample in the present research can basically reflect trip features in Beijing, which is quiet typical.

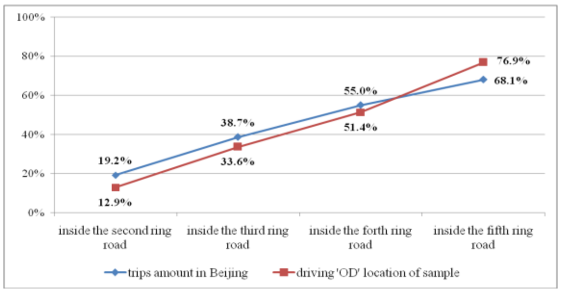

Figure2: The driving OD distribution of sample compared with trips amount in Beijing

3.2 Driving patterns

The main result of driving patterns of private passenger vehicle in Beijing is shown in table 3.

Table3: The main result of driving patterns of private passenger vehicle in Beijing

	weekday	weekend	Regular day (weekday & weekend)
Daily driving range (km)	36.9	48.7	40.2
Singe-trip driving range (km)	16.5	18.7	17.2
Daily driving time(h)	1.56	2.16	1.72
Daily parking time(h)	5.95	3.01	5.08
Daily driving frequency	2.23	2.60	2.33

(1) Daily driving range

Daily driving range stands for the distance a vehicle travels from origin to destination in a day. In Beijing, the average daily VKT of private passenger vehicles at weekend (48.7km) is 32.0% higher than that in weekday (36.9km). In total, the average daily VKT is 40.2 km.

(2) Singe-trip driving range

Singe-trip driving range refers to the distance a vehicle travels from the driving origin to destination of each trip. Average singe-trip driving range of private passenger vehicle in Beijing is 16.5km in weekday and 18.7km at weekend, with 2.2km in difference. In total, the average driving range of singe trip is 17.2km.

(3) Driving time and parking time

Driving times refers to the time a vehicle costs from the driving origin moment and destination moment of each trip. Parking time means the parking hours during an OD, excluding the hours between the last parking in the previous day and the first driving in the coming day. Daily driving time and parking time is 1.72h and 5.08h. Compared with the values at weekend, driving time in weekday is 0.6h shorter while parking time is 3h longer.

(4) Driving frequency

Driving frequency equates the number of trips in a day. The private passenger vehicles in Beijing travel 2.33 trips. The value of driving trips at weekend is 0.37 more than that in weekday.

4 Discussion

4.1 Distribution of daily driving range

With 3km as an interval, the daily VKT distribution probability and cumulative probability in weekday, weekend and regular day are plotted in figure 3. Daily VKT in a regular day is mostly less than 100 km and intensively distributed in the interval of 15km~18km, accounting for 6.4%. Cumulative probability exhibits that the daily VKT value of 11.9km, 23.9km and 51.7km will cover about 25%, 50% and 80% of the daily travel, while the values are 15.2km、36.4km and 73.2km at weekend. In a whole, the daily VKT value which covers 25%, 50% and 80% of the driving range are 12.7km, 27.6km and 57.5km, respectively.

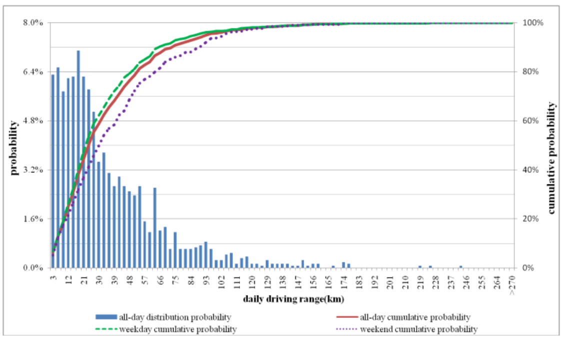

Figure3: Daily vehicle kilometres travelled distribution

In order to fitting of daily driving range, as an alternative approach, the gamma distribution is suitable for representing private passenger vehicle travel due to its non-negativity and skewness flexibility [13]. Through gamma fitting of daily driving range, the probability density function is defined as follow:

$$p(r)=\begin{cases}\frac{\lambda^{\alpha}}{\Gamma(\alpha)}r^{\alpha-1}e^{-\lambda r}, & r\geq 0\\ 0, & r<0\end{cases} \tag{1}$$

$\Gamma(\alpha)$ means the gamma function:

$$\Gamma(\alpha)=\int_{0}^{+\infty} r^{\alpha-1}e^{-r}\mathrm{d}r \tag{2}$$

Where r is the daily VKT (km), $p(r)$ is the probability density when the daily VKT is equal to r , α is the shape parameters and λ is the scale parameters. Using the maximum likelihood estimates, the gamma distribution fitting parameters for the daily VKT of private passenger vehicle in Beijing is obtained as table 4. The Pearson correlation coefficients between the fitting value and actual value are very close to 1, showing that the daily driving range of private passenger vehicles in Beijing corresponds with gamma distribution.

Table4: The gamma distribution fitting parameters for the daily VKT in Beijing

parameters	Regular day	weekday	weekend
α	1.2038	1.2022	1.2519
λ	0.0359	0.0383	0.0320

In conclusion, EV may cover 50%, 80%, and 90% of the daily driving trip with AER respectively set as 30km, 60km, and 80km. If considering the driving trip at weekend only, it may cover 44%, 72%, and 83% of the daily driving trip when AER is set as 30km, 60km, and 80km separately

4.2 Distribution of single-trip driving range

In addition to single-trip VKT, single-trip max-range and min-range require special concern as well. The distribution of them is plotted in figure 4. We find that max-range and min-range trip in a day is 24.3km and 13.7km in average. And min-range trips are mostly short-distances trip from 0~6km, while max-range trips are from 15km~18km. Cumulative probability suggests the single-trip VKT value of 8.9km, 22.8km and 50.2km will respectively cover about 50%, 80% and 95% of the single-trip travel. If considering the max-range of a single-trip in a day only, VKT values which cover 50%, 80% and 95% of single-trip are 14.9km, 31.6km and 67.1km separately.

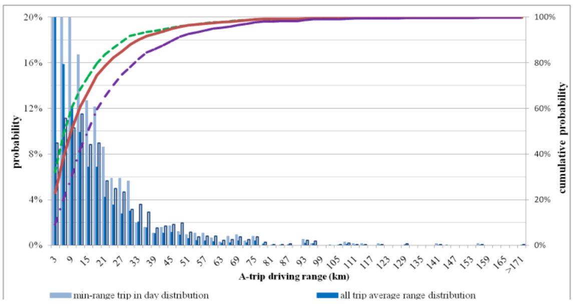

Figure4: Single-trip vehicle kilometres travelled distribution

Thus, BEV may cover 95% single-trip with AER set at 50km based on the single-trip range in average. Considering the max-range of a single trip, BEV may also cover the same with AER set at 70km. Therefore, if the BEV is charged reasonably, its applicability and endurance will be better.

4.3 Driving time

The driving time, also called OD hour, means the driving origin moment and the destination moment of each trip. A three-dimensional diagram is plotted in Figure 5 by combining driving origin moment or destination moment with driving range. We can see that there are 2 rush-hours for driving origin moment in a day: 7am -9am & 5pm-7pm. The driving range centers around 15km and 10km in the first and second rush-hour. There is a minor rush-hour around midday, most of which is less than 5km. Similarity, rush-hours for driving destination moment also happen twice, which is one hour later than the rush-hour of driving origin moment. This distribution reflects people's commuting driving. Driving time and range are quite similar on the way to work, and there is often a short trip at noon. Then people have more choices in driving range and time after work.

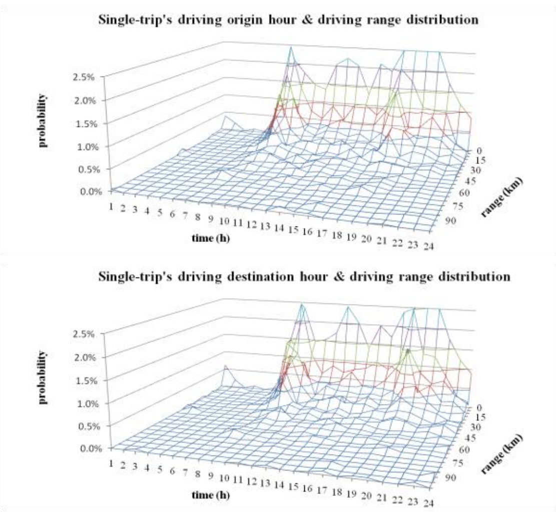

Figure5: single-trip's OD hour & driving range distribution

Driving origin moment and the driving destination moment in weekday and weekend are plotted in figure 6. We find that OD hour has two obvious peaks in weekday. Over 15% of trips start from 7am ~ 8am and stop from 8am ~ 9 am, and over 13% of trips start at 5pm~6pm and stop at 6am~7pm. At weekend, the OD hour, around 8 am to 10 pm, is quite decentralized. The most common OD hour is from 3pm~4pm, accounting for about 10%.

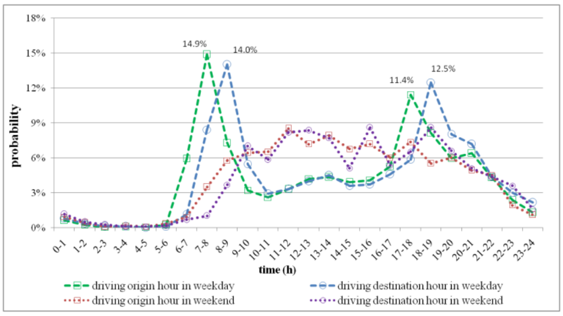

Figure6: The driving OD hour of weekday & weekend distribution

4.4 Distribution of driving frequency

Relation between driving frequency and daily driving range is plotted in figure 7. We can find that 70% vehicles travel no more than 2 trips per day in weekday, while the data is about 55% at weekend. This indicates that people have more choices in driving frequency at weekend. Driving range is directly proportioned to driving frequency in weekday and fluctuates at weekend as driving frequency increasing, showing that people also have more choices in trip distance at weekend.

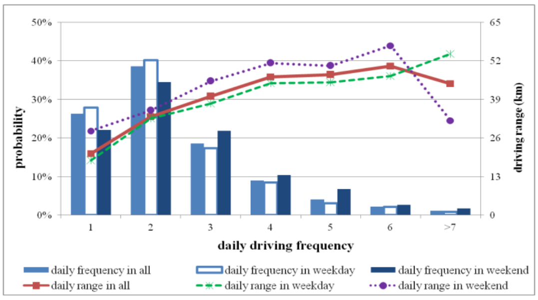

Figure7: The driving OD hour of weekday & weekend distribution

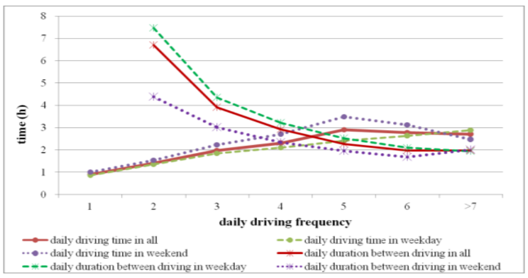

Figure8: The relation of daily driving time & stopping time

In addition, relation between driving frequency and daily driving time or parking time is shown in figure 8, indicating a longer driving time and parking time in weekday than at weekend. Driving time is proportioned to driving frequency, while parking time is inversely proportional.

If BEV's battery could be charged every time the vehicles stop, it is in line with law that driving range and time grow with driving frequency, that is to say, higher frequency and more charging leads to a longer driving range and time. Nevertheless, fast charging system in BEV is required, for parking time shortens with driving frequency increasing.

5 Conclusion

The GPS-based research on driving range and patterns of private passenger vehicles in Beijing of the year 2012-2013 indicates that:

1) Daily driving range of weekday, weekend and regular day are 36.9km, 48.7km and 40.2km, respectively.

2) Single-trip driving range is about 18km. The max-range and the min-range are 24.3km and 13.7km.

3) Driving time and parking time are 1.56h and 5.59h in weekday, while at weekend they are 2.16h and 3.01h. There are 2.23 trips in weekday and 2.60 trips at weekend.

4) Rush-hour happens twice in a weekday: 7am - 9am & 5pm-7pm, which is regular, while there is no obvious rush hour at weekend.

5) BEV may cover almost all the single-trip and 80% of the daily travel with AER set as 60km.

References

[1] Dennis L, *How did GM determine that 78% of commuters drive less than 40 miles per day?* < GM-Volt.com>. (accessed 01.03.12)

[2] Brett Williams, Elliot Martin, et. Al., *Plug-in-Hybrid Vehicle Use, Energy Consumption, and Greenhouse Emissions: An Analysis of Household Vehicle Placement in Northern California*, Energies, 2011, 4: 435–457

[3] Han HAO, Hewu WANG, Minggao OUYANG, *Fuel conservation and GHG (Greenhouse gas) emissions mitigation scenarios for China's passenger vehicle fleet*, Energy 36(2011), 6520-6528

[4] Han HAO, *Research on the Modeling of China's Vehicle Ownership and Automotive Energy System*, Tsinghua University, Beijing, 2012 (in Chinese)

[5] USDOT, *Summary of travel trends 2009 National Household Travel Survey*, U.S. Department of Transportation Federal Highway Administration, 2011

[6] Nathaniel S. Pearre, Willett Kempton, et. Al., *Electric vehicles: How much range is required for a day's driving?*, Transportation Research Part C, doi:10.1016/j.trc.2010.12.010

[7] William J. Smith, *Can EV (electric vehicles) address Ireland's CO2 emissions from transport?*, Energy, 2010,35:4514-4521

[8] Beijing Transportation Research Center, *The 2011 annual report of Beijing traffic development*, Beijing: Beijing Transportation Research Center, 2011 (in Chinese)

[9] Shanghai City Transportation Planning Institution, *The report of the 4th traffic comprehensive survey in Shanghai*, Shanghai: Shanghai City Transportation Planning Institution, 2009 (in Chinese)

[10] Nadine S., Kay W., *Identifying trips and activities and their characteristics from GPS raw data without further information*, In: The 8th international conference on survey methods in transport, Annecy, May25-31, 2008

[11] Chunfu SHAO, *Traffic planning*, Beijing: China Railway Publishing House, 2008 (in Chinese)

[12] Beijing Municipal Commission of Transport, Beijing Transportation Research Center, *The report of the 3rd traffic comprehensive survey in Beijing*, Beijing: Beijing Transportation Research Center, 2007 (in Chinese)

[13] Greene, D. L., *Estimating Daily Vehicle Usage Distributions and the Implications for Limited-Range Vehicles*, Transportation Research Part B, Methodological, 19(4): 347-358

Authors

Hewu WANG, Associate Professor, Deputy Director of the China-US Clean Vehicle Consortium, Tsinghua University, China.

Lvwei WU, Master, Department of Automotive Engineering, Tsinghua University, China.

Cong HOU, Ph. D. Candidate, Department of Automotive Engineering, Tsinghua University, China.

Minggao OUYANG, Professor, Directing the State Key Laboratory of the Automotive Safety and Energy, Tsinghua University, China.