Poster: Understanding Long-Term Mobility and Charging Evolving of Shared EV Networks

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ABSTRACT

Due to the ever-growing concerns over air pollution and energy security, many cities have started to update their taxi fleets with electric ones. In this paper, we perform the first comprehensive measurement investigation called ePat to explore the evolving mobility and charging patterns of electric vehicles. Our ePat is based on 5-year 4.8 TB taxi GPS data, 240 GB taxi transaction data, and metadata from 117 charging stations, during an evolving process from 427 electric taxis in 2013 to 13,178 in 2018. Moreover, ePat also explores the impacts of various contexts and benefits during the evolving process. Our ePat as a comprehensive investigation of the electric taxi network mobility and charging evolving has the potential to advance the understanding of the evolving patterns of electric taxi networks and pave the way for analyzing future shared autonomous vehicles.

CCS CONCEPTS

• **Networks** → **Network measurement**; *Mobile networks*; Cyber-physical networks.

KEYWORDS

Electric vehicle; mobility pattern; charging pattern; evolving experience; shared autonomous vehicle

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1 INTRODUCTION

In the vision of smart cities, vehicle electrification has become inevitable since it contributes to significant emission reduction for better air quality and less energy consumption [4, 5]. Compared to personal cars, taxis as shared vehicles have high gas consumption and emissions due to their long-time daily operations. For example, replacing a conventional gas taxi with an Electric Taxi (ET) creates an emission impact that is equivalent to replacing eight New York City personal cars with electric vehicles [2]. It provides a higher incentive for city governments to replace conventional gas taxis with ETs. In the recent decade, many cities around the world have initiated the process of taxi electrification, e.g., New York City, London, Beijing, and Shenzhen [3]. Among these cities, the Chinese city Shenzhen has started the taxi electrification process from 2010 and achieved the largest ET network in the world by 2017. In particular, the number of ETs in Shenzhen has increased from 50 in 2010 to 12,518 in 2017, and it is projected to be over 18,000 in 2020, becoming an ET-only taxi network.

In this paper, we perform a comprehensive measurement investigation called ePat to explore the evolving patterns of the ET network based on multi-source datasets. With ePat, we systematically measure the mobility and charging evolving patterns of ETs, combined with the accessory charging network evolving patterns. Finally, an in-depth discussion is made on the potential applications of our measurement investigation for other cities that plan to promote large-scale ET fleets and future shared autonomous vehicles.

2 METHODOLOGY

In this section, we introduce our investigation methodology.

2.1 Data Description

For this project, we obtain four datasets from Shenzhen, which is a city with more than 12 million population and an area of 792 mi². The time span of these datasets is from September 2013 to July 2018, during which the percentage of ETs among all taxis has increased from 2.7% to 65.2%. The four datasets include 4.8 TB taxi GPS data, 240 GB taxi transaction data, 117 charging station data, and the urban partition data with 491 regions of Shenzhen.

Figure 1: Operation and charging patterns of electric taxis

Figure 2: The ET coverage density evolving pattern in 491 urban regions

2.2 ET Contextualization

We leverage Figure 1 to illustrate how we put the operation and charging patterns of ETs into contexts from three dimensions, i.e., spatial, temporal, and energy. As shown in Figure 1, the period from t_0 to t_5 is defined as a complete operation and charging cycle.

We denote the time from the charging station to pick up the first passenger as $t_{picking} = t_1 - t_0$, and the period from the first pickup after a charge to the last drop-off before the next charge as the $t_{operation} = t_2 - t_1$. We denote the time of seeking a charging station as $t_{seeking}$, which is $t_3 - t_2$. We leverage the $t_{waiting}$ to stand for the waiting period for an available charging point (i.e., $t_{waiting} = t_4 - t_3$), followed by the charging time in the station (i.e., $t_{charging} = t_5 - t_4$). We define a charging activity as the process of a driver starts to seek a charging station (i.e., t_2) and until he/she finishes the charging activity (i.e., t_5), which is $t_{seeking} + t_{waiting} + t_{charging}$. An operation activity includes the overhead after charging $t_{picking}$ because it happens after charging, so the duration of an operation activity is $t_{picking} + t_{operation}$.

2.3 Quantification Metrics

Mobility Evolving Measurement: We investigate the mobility pattern evolving of the ET network from both spatial and temporal perspectives. We define the ET coverage density and the daily operation distance for quantification.

Charging Evolving Measurement: For the charging measurement, we investigate the $t_{waiting}$ and $t_{charging}$ evolving patterns. We also investigate the charging supply and demand evolving patterns from both temporal and spatial aspects over five years, from which some insights are derived.

3 INVESTIGATION RESULTS

3.1 Mobility Evolving

ET Coverage Density Evolving: As in Figure 2, the darker red part means fewer ET activities in this region and the lighter yellow stands for more ET activities in this region. We also show the number of GPS records distribution in these regions in the northeast corners. We have the following observations: (i) The ET density in Shenzhen has increased significantly during the five years, especially from 2015 to 2017, almost all the regions have a higher ET density compared to the previous year, which was also observed from the distributions. Quantitatively, the growth of the density from 2015 to 2017 has increased 25 times compared with the previous growth; (ii) the ETs are gathered in the central business district (CBD) area from 2013 to 2015, but more ETs start to operate in the suburban areas after 2015.

3.2 Charging Evolving

3.2.1 Charging Activity Evolving. As shown in Figure 3, the overall trend for $t_{waiting}$ is growing. We then investigate causalities behind this phenomenon and one possible reason is that the number of ETs increased too fast; whereas the increase of charging infrastructure cannot keep up. Specifically, from 2013 to 2014, the number of ETs had increased about two hundred, but the number of charging points only increased by 2, which causes waiting time increases. From 2015 to 2017, the number of ETs had dramatically increased; whereas only limited charging stations are built.

Figure 4 shows the average $t_{charging}$ evolving pattern, which shows most drivers have a relatively stable charging time. Since the $t_{seeking}$ is mainly related to the urban traffic

Figure 3: T_{waiting} evolving **Figure 4: T_{charging} evolving** conditions, which is decided by many non-mobility factors, e.g., government traffic management and urban road network evolving, we do not report it as it is difficult to find obvious evolving patterns even after an in-depth investigation.

Figure 5: Charging station deployment evolving

3.2.2 Charging Supply Evolving. In Figure 5, we visualize the evolving pattern of charging supply for ETs in Shenzhen from year 2013 to 2018 in 491 urban regions. We found the total number of charging stations has increased from 31 in 2013 to 117 in 2018. Intuitively, ET charging stations are unevenly distributed in Shenzhen, and the general trend of the charging station deployment is from the urban areas to suburban areas, with an accelerated deployment speed from 2013 to 2018, especially from 2016 to 2018, during which more than 60 charging stations were deployed.

3.3 ET Benefits

Based on [1], we consider the real-world traffic conditions (e.g., travel speed), the daily travel distance of ETs, and daily travel time of ETs to accurately estimate CO₂ emission reduction of the ET network, which is represented by

$$E = K_c * \left[0.3T + 0.028D + 0.056 \sum_{i=1}^k (\delta_i * (v_{i+1}^2 - v_i^2)) \right] \quad (1)$$

where E is the CO₂ emissions (g); T is the travel time of taxis (s); D is the travel distance of taxis (m); K_c is the coefficient between gasoline consume and CO₂ emissions, which is 2322g (CO₂)/liter(gasoline) for Shenzhen taxis; v_i is the speed at time i (m/s); δ_i is a tow-value indicator, taking the value 1 when accelerating ($v_{i+1} > v_i$) otherwise 0 ($v_{i+1} \leq v_i$).

From Figure 6, we found there is more ETs deployment from June 2016, which explain a major CO₂ reduction. Especially in the last two months of 2017, the number of ET has increased significantly, e.g., in December 2017, the CO₂ reduction is close to 1.8 million tons.

Figure 6: CO₂ reduction

4 INSIGHTS

In this section, we provide a few insights we obtained in our measurement study. (i) **Charging Station Deployment:** If it is feasible to deploy large stations in urban CBD area for other cities, it would be beneficial for promoting their large-scale ET networks; if it is hard to place large stations in CBD areas due to some reasons (e.g., land resources unavailable), more median/small charging stations with less than 40 charging points may be placed in some important suburban areas (e.g., airports and transportation hubs), to improve the overall charging efficiency. (ii) **ET Benefits:** The overall emission reduction can be beneficial for public health and air quality, which is important for a sustainable society.

5 CONCLUSION

In this paper, we conduct the first work to understand the long-term ET network evolving mobility and charging patterns based on the ET network in the Chinese city Shenzhen, which includes more than 13,000 ETs and 117 charging stations. We provide a few insights regarding the evolving process of charging station deployment and utilization, ET coverage density, operation, and mobility patterns under various contexts. We also quantify the emission reduction and driver income benefits of the ET network based on their mobility patterns.

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