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Using mobility information to perform a feasibility study and the evaluation of spatio-temporal energy demanded by an electric taxi fleet

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ABSTRACT

Half of the global population already lives in urban areas, facing to the problem of air pollution mainly caused by the transportation system. The recently worsening of urban air quality has a direct impact on the human health. Replacing today's internal combustion engine vehicles with electric ones in public fleets could provide a deep impact on the air quality in the cities. In this paper, real mobility information is used as decision support for the taxi fleet manager to promote the adoption of electric taxi cabs in the city of San Francisco, USA. Firstly, mobility characteristics and energy requirements of a single taxi are analyzed. Then, the results are generalized to all vehicles from the taxi fleet. An electrifiability rate of the taxi fleet is generated, providing information about the number of current trips that could be performed by electric taxis without modifying the current driver mobility patterns. The analysis results reveal that 75.2% of the current taxis could be replaced by electric vehicles, considering a current standard battery capacity (24–30 kWh). This value can increase significantly (to 100%), taking into account the evolution of the price and capacity of the batteries installed in the last models of electric vehicles that are coming to the market. The economic analysis shows that the purchasing costs of an electric taxi are bigger than conventional one. However, fuel, maintenance and repair costs are much lower. Using the expected energy consumption information evaluated in this study, the total spatio-temporal demand of electric energy required to recharge the electric fleet is also calculated, allowing identifying optimal location of charging infrastructure based on realistic routing patterns. This information could also be used by the distribution system operator to identify possible reinforcement actions in the electric grid in order to promote introducing electric vehicles.

1. Introduction

More than a half of the world population is living in crowed cities, attracted by better opportunities [1], but this high concentration of human beings has led to huge unsolved problems like unplanned housing, water and energy availability, urban waste, access to basic services, stress on the public infrastructure and water and air quality [2].

Air pollution is responsible for the significant growth in chronic health problems on the urban population like respiratory and heart diseases [3]. Most of these problems are directly related to transportation systems [4]. Conventional internal combustion engine (ICE) vehicles are responsible for the emission of 73% of the total urban air pollutants [5]. Introducing electric vehicles (EVs) in big cities can be a key factor to reduce these pollutant emissions [6]. Depending on the electricity generation mix of a specific region, the GHG emissions can even increase if a widespread adoption of EV are promoted when a primary source of electric power is based on fossil fuel generation [7].

Governments are promoting the replacement of ICE vehicles with EVs to reduce the cities' greenhouse gas (GHG) emissions and pollutants. Different initiatives have been developed in Europe [8,9], USA [10] and China [11] among others. This transition can be led by public urban fleets, such as buses, postal delivery vehicles or taxis, because these type of vehicles travel short and repetitive routes and many of these toxic pollutants are concentrated in the same areas of the city that have a high density of urban fleet movements [12].

EVs could provide positive effects for the whole urban population: improvement of the air quality in urban areas, reduced noise pollution,

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and a significant reduction of the urban temperature due to the reduction of heat emission [13]. This transition not only benefits citizens, but can also benefits fleet operators: EVs have a higher initial cost of purchasing, but they have a lower total cost of ownership. The operational running costs are significantly lower than for ICE vehicles, due to reduced fuel spending, lower maintenance and other financial benefits (i.e. tax reduction and other government incentives) [14]. An EV fleet also helps to strength the company's brand image, promoting a social environmental responsibility. The replacement of ICE fleet vehicles with EVs requires a detailed study by the fleet manager, taking into account the fleet's whole life cost.

There are two main limiting factors for the adoption of EVs: the purchase price and the limited range. The first restriction can be solved through taxation and other financial benefits promoted by public institutions. The second restriction can be solved through an analysis of the real fleet mobility requirements, providing a deep understanding of the operational patterns of the real vehicles.

From this information it is possible to evaluate the potential of EVs to meet the fleet mobility requirements, helping the fleet operator to make a seamless transition to a zero-emission vehicle fleet. With the current increasing volume of mobility data available, this potential can be performed through a data-driven analysis.

GPS traces have been previously used in transportation research to validate travel surveys [15] and analyze traffic intensity and movement speed in cities [16].

In [17] GPS traces from ICE light vehicles provided by a private insurance company have been used to evaluate the potential of EVs to meet the current mobility demand in two different Italian cities. In this analysis, the potential electric energy demand is calculated based on fixed consumption values obtained from the car manufacturers or by the US Environmental Protection Agency (EPA) tests, depending of the type of EV considered.

In other works, GPS taxi traces have been applied to evaluate the waiting time of empty taxis [18] for nearest pick-up areas recommendation [19,20] and also to discover spatio-temporal cluster patterns [21]. Specific GPS taxi traces has been used to understand the operational and charging behaviors of electric taxis, identifying the main differences with conventional ICE taxi vehicles [22].

In this paper, real mobility taxi GPS traces from San Francisco (USA) are analyzed to evaluate the possible adoption of EVs in a real taxi fleet. In Section 2, the proposed method is described in detail. In Section 3 a feasibility study is performed, where firstly, a single EV taxi is analyzed and then, this analysis is extended to the rest of the vehicles that compose this taxi fleet. An *electrificability rate* of the taxi fleet is generated, providing information about the number of current trips that could be performed by EVs without modifying the current taxi mobility patterns. Using the expected energy consumption information, the total spatio-temporal demand of electric energy required to recharge the EV fleet is also evaluated. This information can be used to identify optimal location of the charging infrastructure and additionally, this data could be used by the distribution system operator (DSO) to identify possible reinforcement actions in the electric grid. Finally, conclusions and discussions are provided in Section 4.

2. Methods

For this study, the mobility data description is initially presented. Then, several calculations are performed to study the real mobility of each vehicle (evaluation of the travelled distance, speed, etc.). With this information, different charging event opportunities are evaluated, determining the stops with a time duration that exceed half an hour. It is assumed that during these periods, EV taxis will be charged from 5 to 80% nominal capacity with a DC fast charger [23]. The location and the total duration of these stops are also registered.

The next step is to develop an EV consumption model to estimate the expected electric energy consumption. This model takes into account the driving distance, the speed, the taxi status and the terrain elevation.

2.1. GPS data description

Taxi companies around the world have begun to install GPS tracking devices to analyze operational patterns of EV [18–20] and provide an efficient taxi dispatch to their customers [22,23].

The data utilized in this work consists of 8.6 million GPS traces from 466 ICE taxis collected over 30 days (May 17th to June 15th, 2011) in the city of San Francisco, USA. Each trace contains latitude and longitude coordinates, a binary variable indicating the taxi occupancy status (1 when the taxi is carrying a customer and 0 when it is empty) and finally, a timestamp in UNIX time (representing the number of seconds that have elapsed since January, 1st, 1970) [24]. The average timestep between two consecutive samples is around 90 s.

The GPS data was analyzed before using it and some inconsistences were detected, removing the data corresponding to six vehicles from the original 466 data set.

2.2. Mobility calculation

The recorded GPS traces do not contain information about the terrain elevation, but this is one of the main factors influencing the vehicle consumption. Therefore, it is important to obtain this data and add it to the GPS traces for further consideration in the analysis. In this work, the altitude of the latitude-longitude data set has been extracted from US Geological Survey National Elevation Dataset [25].

With this additional information, the total distance between two consecutive GPS traces is evaluated, as it is described in Fig. 1. Firstly, the distance between two consecutive coordinates over the earth's surface is calculated based on the basis of spherical earth and ignoring the ellipsoidal effects, which is accurate enough for this work, where two consecutive coordinates are only separated by tens of kilometers. There are several ways to calculate this distance: using a planar approximation, the Haversine formula or the spherical law of cosines. This last option was used in this work [26]. With this information, and the elevation of both coordinates, the real travelled distance and the elevation angle (also called, angle of the driving surface, α, in the model) are finally evaluated.

Adding up these intermediate distances between consecutives coordinates, will allow to calculate the total distance travelled during a particular time period.

The average speed between two consecutive latitude-longitude coordinates is also evaluated, providing additional information about the taxi's speed.

2.3. Understanding taxi mobility behavior and detecting the charging event possibility

It is important to clearly understand the real taxi mobility behavior to perform the feasibility studies for EV deployment in a taxi fleet. For this study, it is assumed that the mobility behavior would not change when the taxi fleet operator replaces its conventional ICE vehicles with new EV ones. This assumption ignores the possible variation in the EV use due to its deployment.

Analyzing the current taxi mobility, it is observed that most vehicles are operating during all day. The reason is that taxi fleet operators always want to maximize their revenues, minimizing the resting time. In this case, taxi cabs belong to a single fleet operator and the drivers who work for it, operate in a double-shift scheme (vehicles are driven 12–16 h per day).

Although most taxis are double-shifted, drivers must take breaks during their working periods. In this work, it has been considered that quick chargers are used to recharge their vehicles during this resting period.