Employing Opportunistic Charging for Electric Taxicabs to Reduce Idle Time

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Motivations

Taxicabs are being replaced with Electric Vehicles (EVs)

India will add 6–7 million EVs by 2020

The U.S. is issuing $55 million to replace internal-combustion buses with EVs
https://www.greentechmedia.com/articles/read/a-boost-for-electric-buses
Motivations

**Expectations:**
Continuously driving without recharge downtime
Pick up passengers efficiently
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**Limitations:**
- Limited battery capacity
- Completely stop and a long time for full recharge
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http://news.ifeng.com/a/20141121/42533900_0.shtml
Motivations

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- Continuously driving without recharge downtime
- Pick up passengers efficiently

**Limitations:**
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- Completely stop and a long time for full recharge

"I can take 5 more requests if not for recharge!"

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Motivations

Traditional operation of an electric taxicab
Motivations

Traditional operation of an electric taxicab

1. Cruising
2. Traveling
3. Seeking a charger
4. Charging
5. Cruising
Motivations

Traditional operation of an electric taxicab
1. Cruising
2. Traveling
3. Seeking a charger
4. Charging
5. Cruising

Expected operation of an electric taxicab
1. Traveling
2. Seeking a charger
3. Charging
4. Traveling
State-of-the-art

Plug-in charger deployment (IEVC’14, TSG’14, TPS’14, TPD’13)
• Cannot reduce charger seeking time and charging time upon battery exhaustion

Taxicab dispatching (UbiComp’11, TPDS’15, TITS’16, SIGKDD’12)
• Cannot reduce taxicabs’ cruising time without passengers on board
State-of-the-art

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• Cannot reduce taxicabs’ cruising time without passengers on board

No previous works can comprehensively save the time wasted on cruising, charger seeking and charging
For taxicabs:
• Relatively determined parking patterns
• Abundant opportunity for stationary charging

For buses:
• Relatively determined driving route
• Abundant opportunity for dynamic charging

Background
Stationary wireless charging for EVs

- For taxicabs:
  - Relatively determined parking patterns
  - Abundant opportunity for stationary charging

- For buses:
  - Relatively determined driving route
  - Abundant opportunity for dynamic charging
Background

Stationary wireless charging for EVs

Opportunistic charging of taxicabs
Research Problem and Challenges

• How to deploy stationary wireless chargers in a city with the minimum cost (i.e., fewest chargers) to ensure the continuous driving of taxicabs, and also offer them enough opportunity of picking up passengers while they park for recharging?
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• **Goal:** maximize taxicabs' probability of picking up passengers and maintain taxicabs' SoC on roads
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• **Rationale**: regions with many and frequent appearance of passengers are better for charger deployment
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• How to measure the likelihood of passenger appearance at each region?

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Our mobility dataset (Jan 1~ Dec 31, 2015) includes:

15,610 taxicabs

Occupancy status = 0: no-occupied
Occupancy status = 1: occupied
Distribution of passenger appearance
Large-scale Taxicab Mobility Dataset for Analysis

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Occupancy status = 0: no-occupied

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Distribution of passenger appearance

Shenzhen city
System Design of PickaChu

Challenges:

• How to measure the likelihood of passenger appearance at each region?
  − Building functionality and passenger appearance
  − Frequency of passenger appearance

• How to calculate electric taxicabs’ SoC on any position?
Challenge 1: Measure the Likelihood of Passenger Appearance

**FACT**

Data analysis observation: building distribution, density and functionalities have impact on distribution of passenger appearance
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Data analysis observation: building distribution, density and functionalities have impact on distribution of passenger appearance

**PROBLEM**

How to use the impact to measure likelihood of passenger appearance?
Challenge 1: Measure the Likelihood of Passenger Appearance

**Solution**

Weighted sum of all building functionalities in a region

\[
\bar{H}_i = \frac{B_i}{B_{\text{max}}} \sum_{c \in C} w(c)P_i(c)
\]
Weighted sum of all building functionalities in a region

$$\bar{H}_i = \frac{B_i}{B_{max}} \sum_{c \in C} w(c)P_i(c)$$

Composition: { Residential (20%), Commercial (5%), Civic (20%), Basics (5%), Professional (10%), Tourism (40%) }

Weights: Residential=0.9, Commercial=0.7, Civic=2.0, Basics=0.2, Professional=4.4, Tourism=0.2

$$B_i = 100, \ B_{max} = 500$$
Challenge 1: Measure the Likelihood of Passenger Appearance

Weighted sum of all building functionalities in a region

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\[ B_i = 100, \quad B_{max} = 500 \]

\[ 100/500 \times (0.9 \times 0.2 + 0.7 \times 0.05 + 2.0 \times 0.2 + 0.2 \times 0.05 + 4.4 \times 0.1 + 0.2 \times 0.4) = 0.23 \]
Challenge 1: Measure the Likelihood of Passenger Appearance

**FACT**

**Data analysis observation:** passenger appearance has patterns with different frequencies
**Challenge 1: Measure the Likelihood of Passenger Appearance**

**FACT**

*Data analysis observation:* passenger appearance has patterns with different frequencies
Challenge 1: Measure the Likelihood of Passenger Appearance

**Data analysis observation:** passenger appearance has patterns with different frequencies

**Problem:** How to extract and use the frequencies to measure likelihood of passenger appearance?
Challenge 1: Measure the Likelihood of Passenger Appearance

**SOLUTION**

Weighted sum of the frequencies of significant patterns
Challenge 1: Measure the Likelihood of Passenger Appearance

Weighted sum of the frequencies of significant patterns
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Weighted sum of the frequencies of significant patterns

Discrete Fourier Transform (DFT)

$$F_i^{DFT}$$
Challenge 1: Measure the Likelihood of Passenger Appearance

**SOLUTION**

Weighted sum of the frequencies of significant patterns

Discrete Fourier Transform (DFT)

\[ F_i^{\text{DFT}} \]

AutoCorrelation Function (ACF)

\[ F_i^{\text{ACF}} \]
Challenge 1: Measure the Likelihood of Passenger Appearance

**SOLUTION**

Weighted sum of the frequencies of significant patterns

- **Discrete Fourier Transform (DFT)**
  \[ F_i^{DFT} \]
- **Final frequencies**
  \[ F_i = F_i^{DFT} \cap F_i^{ACF} \]
- **AutoCorrelation Function (ACF)**
  \[ F_i^{ACF} \]
Challenge 1: Measure the Likelihood of Passenger Appearance

**Solution**

Weighted sum of the frequencies of significant patterns

Discrete Fourier Transform (DFT)

\[ F_i^{DFT} \]

Final frequencies

\[ F_i = F_i^{DFT} \cap F_i^{ACF} \]

\[ \bar{F}_i = \sum_{k=1}^{m} \frac{p_i^k}{\sum_{j=1}^{m} p_i^j} \cdot f_i^k \]

AutoCorrelation Function (ACF)

\[ F_i^{ACF} \]
System Design of PickaChu

Challenges:

• How to measure the likelihood of passenger appearance at each region?
  - Building functionality and passenger appearance
  - Frequency of passenger appearance

• How to calculate electric taxicabs' SoC on any position?
  - Kernel Density Estimator (KDE) based traffic model
Challenge 2: Calculate Electric Taxicabs’ SoC At Any Position

**FACT**

Data analysis observation: taxicabs’ traveling trip lengths follow a certain distribution which determines taxicabs’ SoC at each position.

![Graph showing probability density vs. length of trip]
Challenge 2: Calculate Electric Taxicabs’ SoC At Any Position

**Fact**

**Data analysis observation:** taxicabs’ traveling trip lengths follow a certain distribution which determines taxicabs’ SoC at each position.

**Problem**

How to represent and use the distribution to calculate taxicabs' SoC at any position?
Challenge 2: Calculate Electric Taxicabs’ SoC At Any Position

**SOLUTION**

Build a Kernel Density Estimator (KDE) based traffic model to calculate taxicabs' SoC.
Challenge 2: Calculate Electric Taxicabs’ SoC At Any Position

Build a Kernel Density Estimator (KDE) based traffic model to calculate taxicabs' SoC

- Feed all taxicabs' trajectories to the traffic model to learn the distribution of the trajectory lengths
- Use the distribution to estimate the SoC of taxicabs on any position on the roads
Formulation of Optimization Problem

Calculate electric taxicabs' SoC

Measure the likelihood of passenger appearance
Formulation of Optimization Problem

- Calculate electric taxicabs' SoC
- Measure the likelihood of passenger appearance

**Optimization problem:**
- minimize total deployment cost
- maximize likelihood of picking up passengers at chargers
- maintain taxicabs' SoC at any position
Formulation of Optimization Problem

Optimization problem:
• minimize total deployment cost
• maximize likelihood of picking up passengers at chargers
• maintain taxicabs’ SoC at any position

Output: regions for deploying stationary wireless chargers and the number of chargers
Experiment Setup

Goals:
• Maximize the taxicabs' probability of picking up passengers
• Maintain taxicabs' SoC on roads

Comparison: OCSD (ICDE'15), pCruise (IEEE TPDS'15)
Experiment Setup

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Metrics:
• Ratio of the time of each operation phase
  – Traveling with passenger
  – Cruising without passenger
• Revenue and cost of each taxicab
• SoC of each taxicab per hour during a day
### Experiment Setup

**Goals:**
- Maximize the taxicabs' probability of picking up passengers
- Maintain taxicabs' SoC on roads

**Comparison:** OCSD (ICDE'15), pCruise (IEEE TPDS'15)

**Metrics:**
- **Ratio of the time of each operation phase**
  - Traveling with passenger  –  Seeking for charger
  - Cruising without passenger  –  Charging at charger
- Revenue and cost of each taxicab
- SoC of each taxicab per hour during a day
SUMO is an open source, highly portable, microscopic and continuous road traffic simulator designed to handle large road networks.

A charger example in SUMO  

A SUMO road network
Experiment Setup

Parameter settings

Table 2. Table of parameters.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charging rate $C$</td>
<td>150 kW</td>
</tr>
<tr>
<td>Charger unit price $\omega_0$</td>
<td>$2,000$</td>
</tr>
<tr>
<td>Air drag coefficient $c_w$</td>
<td>0.3</td>
</tr>
<tr>
<td>Rolling resistance coefficient $c_r$</td>
<td>0.01</td>
</tr>
<tr>
<td>Mass of a taxicab $\kappa$</td>
<td>2.020 kg</td>
</tr>
<tr>
<td>Gravity acceleration $g$</td>
<td>9.8 m/s$^2$</td>
</tr>
<tr>
<td>Battery capacity of a taxicab $E_0$</td>
<td>75 kWh</td>
</tr>
<tr>
<td>SoC threshold $\eta$</td>
<td>20%</td>
</tr>
<tr>
<td>Vacant SoC threshold $\theta$</td>
<td>80%</td>
</tr>
<tr>
<td>Maximum speed limit $v_{max}$</td>
<td>60 mph</td>
</tr>
</tbody>
</table>

- Use SUMO to simulate 1,000 taxicabs on road network for 24 hours.
- Actual passengers’ requests happened on July 15, 2015.
Experiment Results

Ratio of the time of each operation phase

![Graph showing the ratio of time for different operation phases (Cruise, Travel, Seek, Charge) for different methods: PickaChu, OptPickaChu, pCruise, OCSD, Baseline.](image)
Experiment Results

Ratio of the time of each operation phase

- PickaChu's travel phase with passengers on board (92%)
- 15% higher than that of pCruise (77%)
- 35% higher than that of OCSD (57%)
- 33% higher than that of Baseline (59%)
Experiment Results

Ratio of the time of each operation phase

• PickaChu's travel phase with passengers on board (92%)
• 15% higher than that of pCruise (77%)
• 35% higher than that of OCSD (57%)
• 33% higher than that of Baseline (59%)

For more details:
1. We designed the first work that aims at both maximally reducing the taxicabs' idle time and supporting the continuous operability of the taxicabs through proper deployment of stationary wireless opportunistic chargers.

2. We conducted extensive trace-driven experiments on SUMO to verify the effectiveness of PickaChu.

3. In future work, we will consider the pattern of passenger appearance to optimize the dispatching and charging of electric taxicabs.
Thank you!
Questions & Comments?

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