Employing Opportunistic Charging for Electric Taxicabs to Reduce Idle Time

Li Yan, Haiying Shen, Zhuozhao Li, **Ankur Sarker**, John A. Stankovic, Chenxi Qiu, Juanjuan Zhao and Chengzhong Xu

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Motivations

Taxicabs are being replaced with Electric Vehicles (EVs)

Shenzhen offers new incentives to boost switch to electric taxis

PUBLISHED : Friday, 24 April, 2015, 2:49pm
UPDATED : Friday, 24 April, 2015, 3:18pm

Montreal is getting an even larger fleet of electric taxis and trucks

Fred Lambert - Sep. 29th 2017 10:30 am ET @FredericLambert

India will add 6-7 million EVs by 2020
http://shaktifoundation.in/report/roadmap-for-the-electrification-of-public-transportation-in-kolkata/

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

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Traditional operation of an electric taxicab

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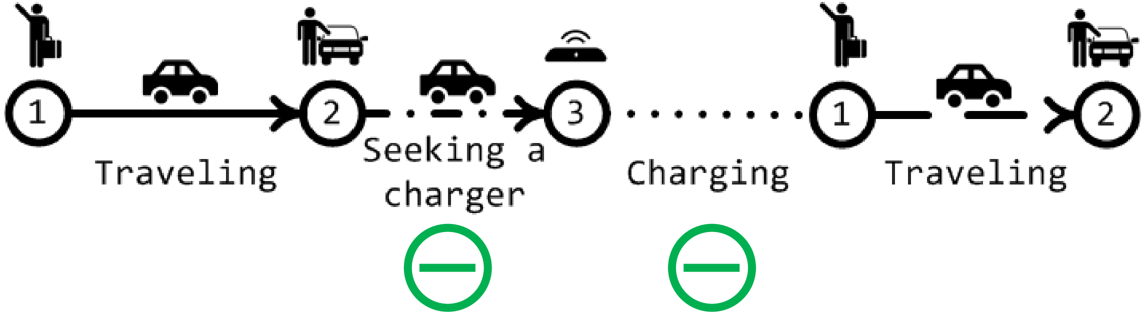
Expected operation of an electric taxicab



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

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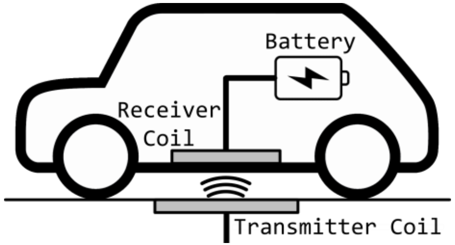
No previous works can comprehensively save the time wasted on cruising, charger seeking and charging

Background

Taxicabs waiting nearby a road segment

Background

Stationary wireless charging for EVs



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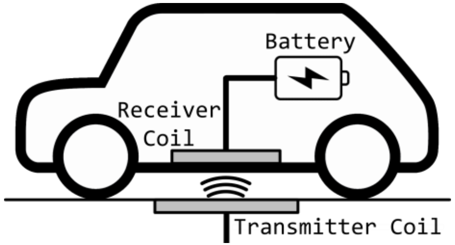

Opportunistic charging of taxicabs

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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Large-scale Taxicab Mobility Dataset for Analysis

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

15,610 taxicabs

Occupancy status = 0: no-occupied

Occupancy status = 1: occupied

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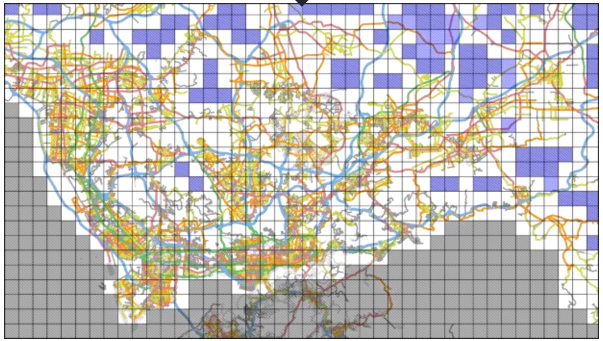

System Design of PickaChu

Challenges:

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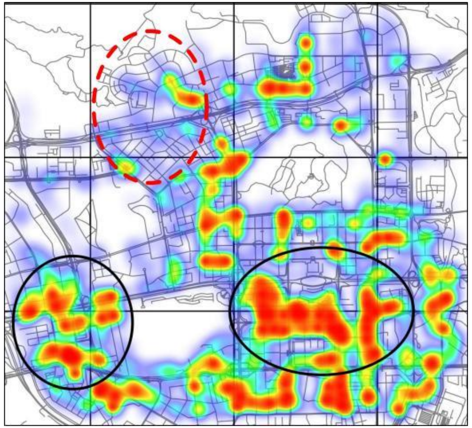

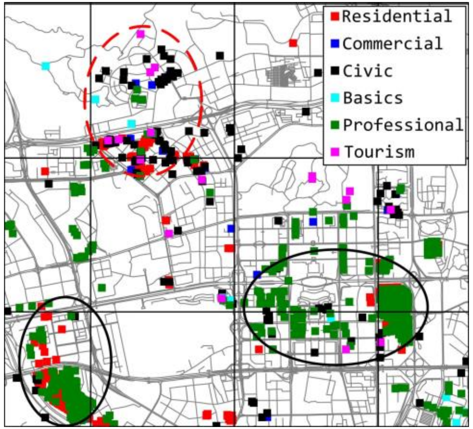

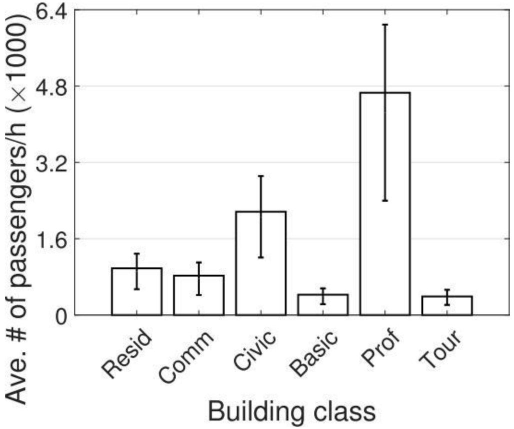

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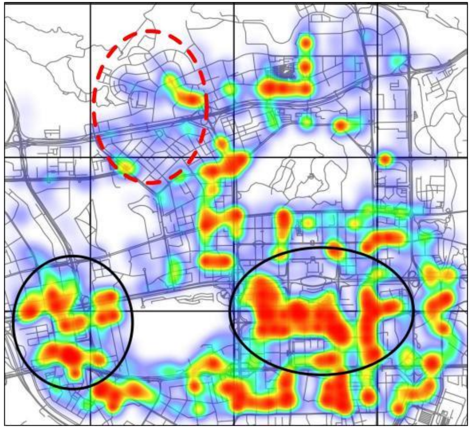
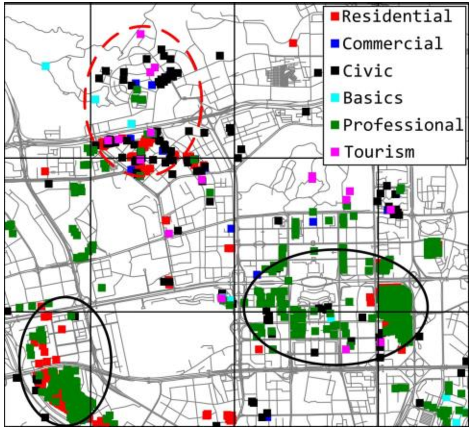
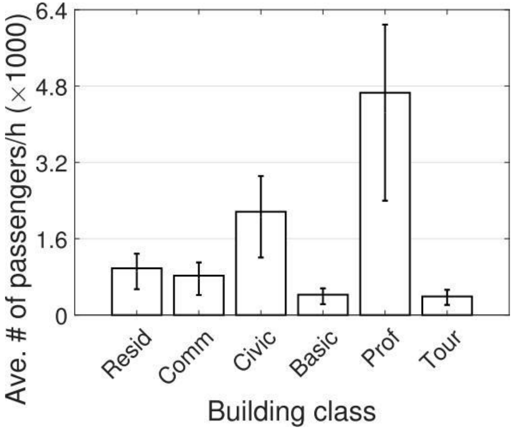
PROBLEM

How to use the impact to measure likelihood of passenger appearance?







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SOLUTION

Weighted sum of all building functionalities in a region

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

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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

$B_i = 100,\ B_{max} = 500$

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100/500×(0.9×0.2+0.7×0.05+2.0×0.2+0.2×0.05+4.4×0.1+0.2×0.4)=0.23

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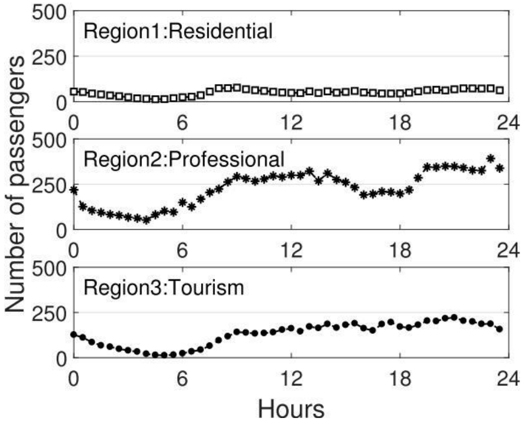

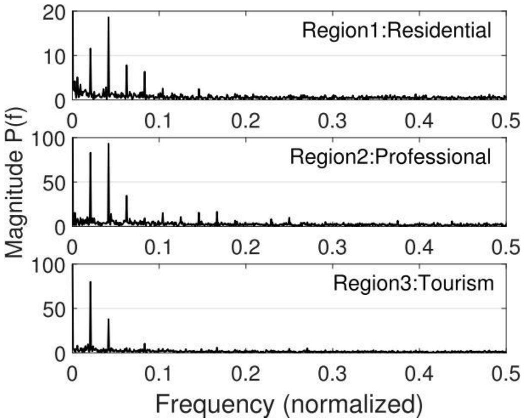

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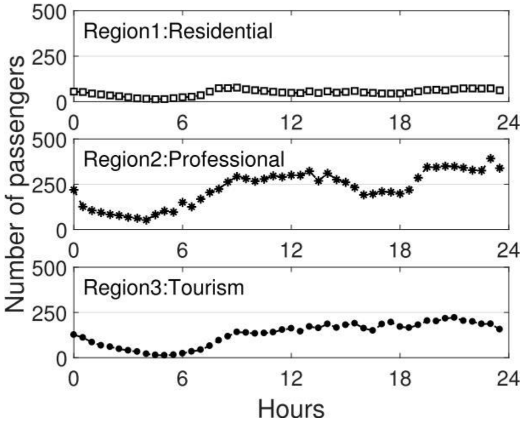
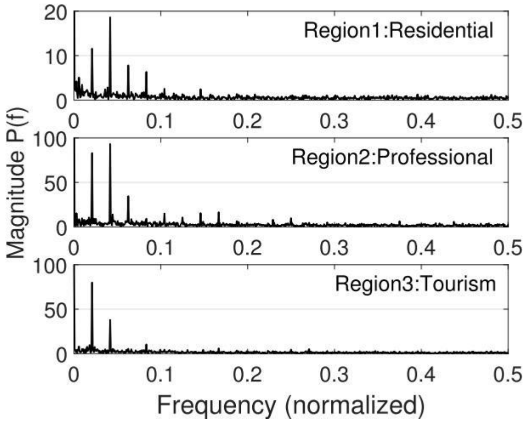
PROBLEM

How to extract and use the frequencies to measure likelihood of passenger appearance?





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Weighted sum of the frequencies of significant patterns

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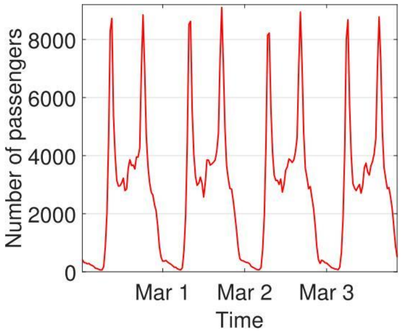

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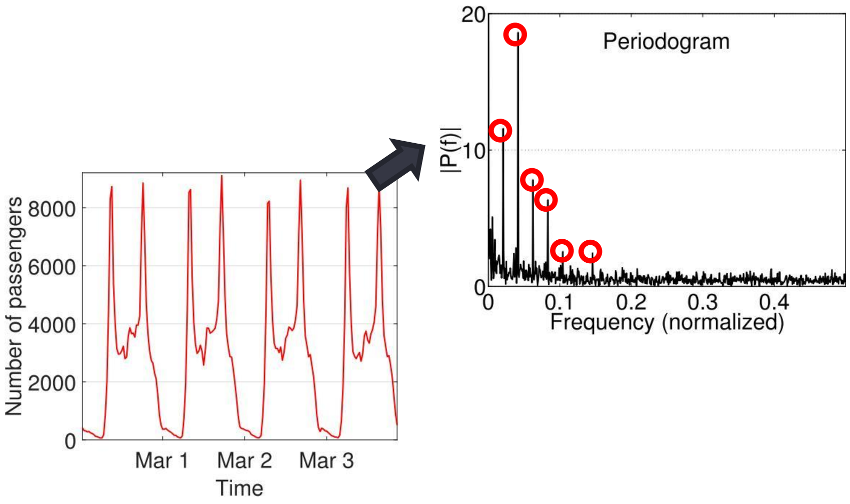

Discrete Fourier Transform (DFT)

F_i^{DFT}

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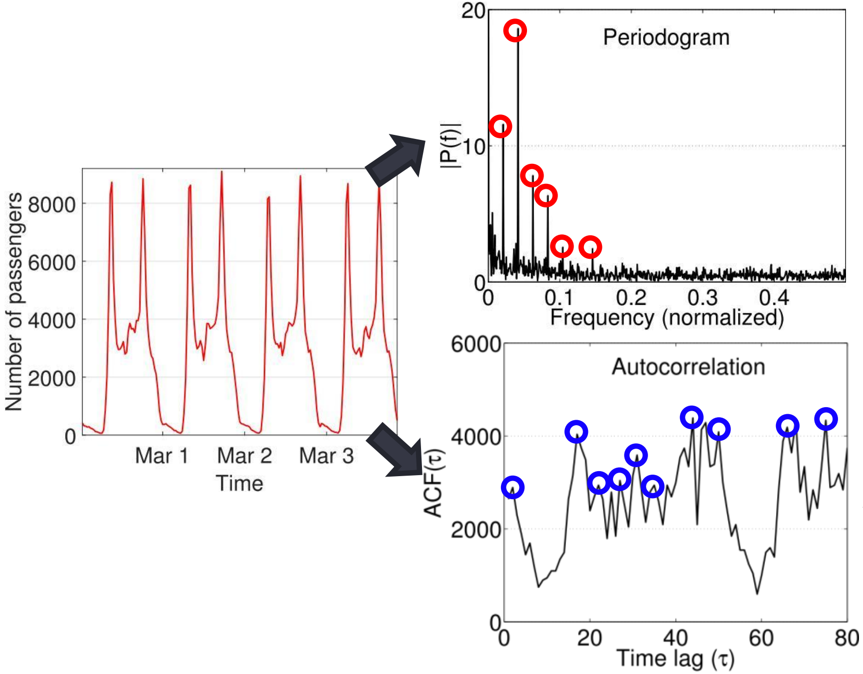

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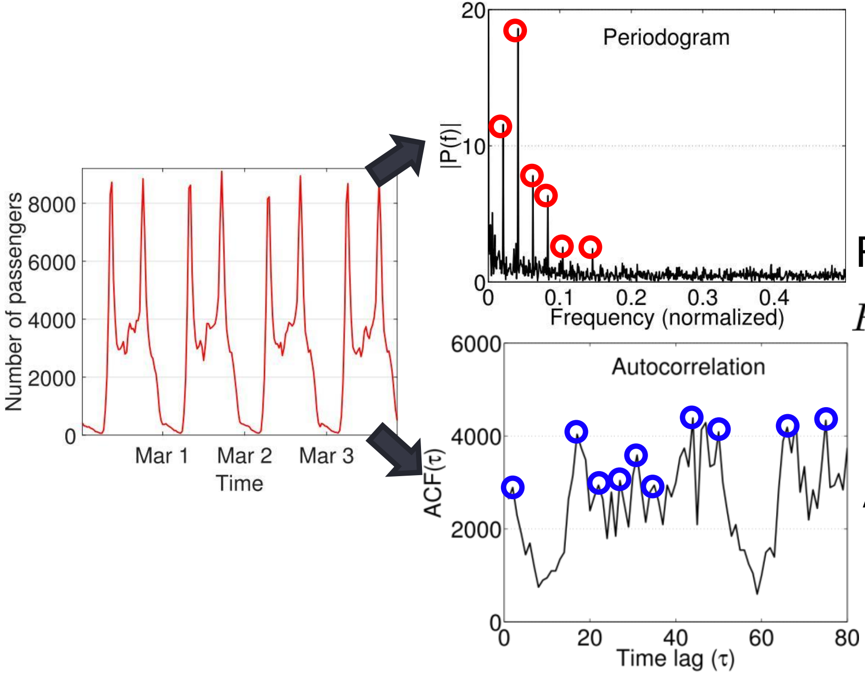

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Final frequencies

$$F_i = F_i^{DFT} \cap F_i^{ACF}$$

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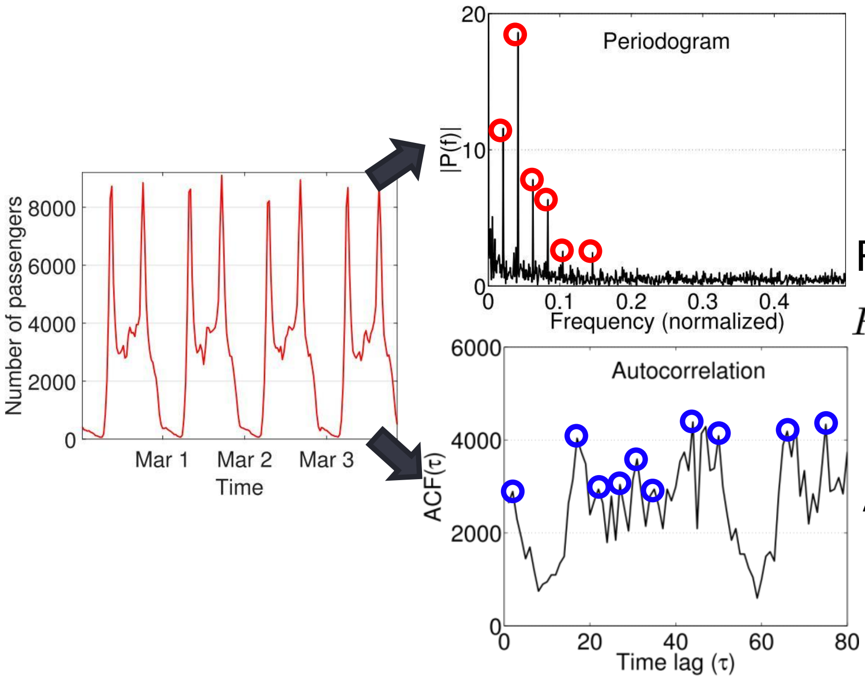

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Final frequencies

$F_i = F_i^{DFT} \cap F_i^{ACF}$

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

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Challenges:

- How to measure the likelihood of passenger appearance at each region?
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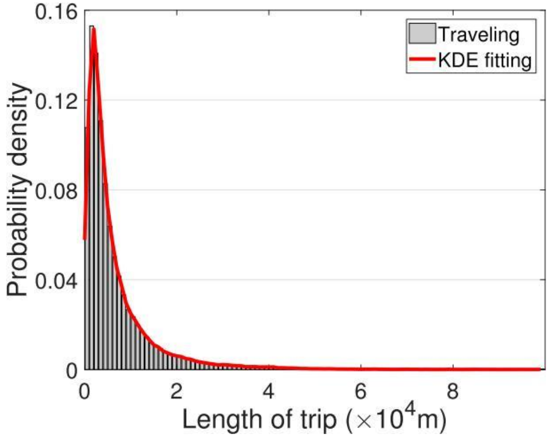
- How to calculate electric taxicabs' SoC on any position?
  - Kernel Density Estimator (KDE) based traffic model

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



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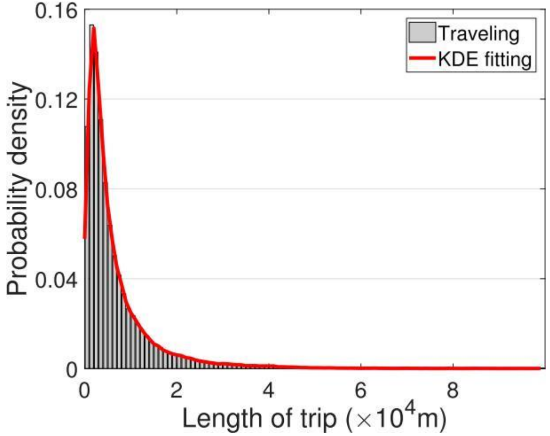
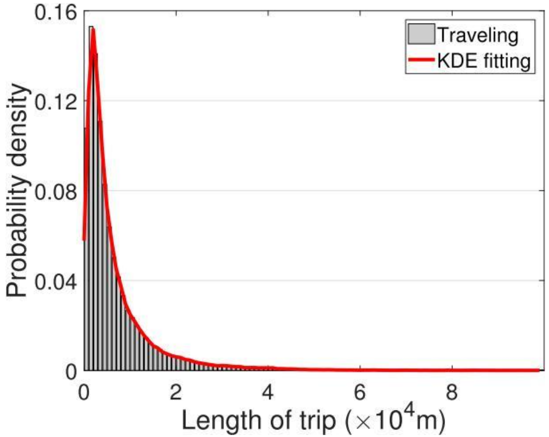


PROBLEM

How to represent and use the distribution to calculate taxicabs' SoC at any position?

Challenge 2: Calculate Electric Taxicabs' SoC At Any Position

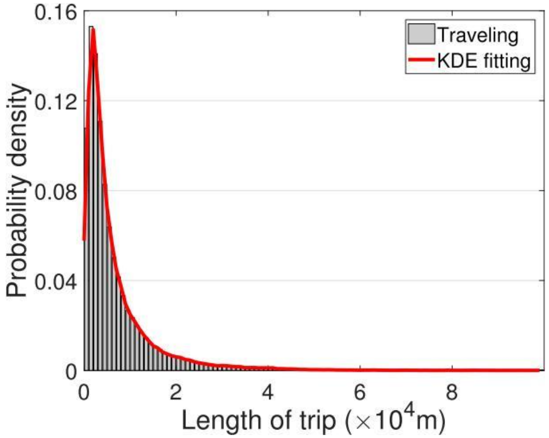
Build a Kernel Density Estimator (KDE) based traffic model to calculate taxicabs' SoC



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

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Optimization problem:

- minimize total deployment cost
- maximize likelihood of picking up passengers at chargers
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Output: regions for deploying stationary wireless chargers and the number of chargers

Experiment Setup

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Goals:

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

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

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Metrics:

- Ratio of the time of each operation phase
  - Traveling with passenger
  - Cruising without passenger
  - Seeking for charger
  - Charging at charger
- Revenue and cost of each taxicab
- SoC of each taxicab per hour during a day

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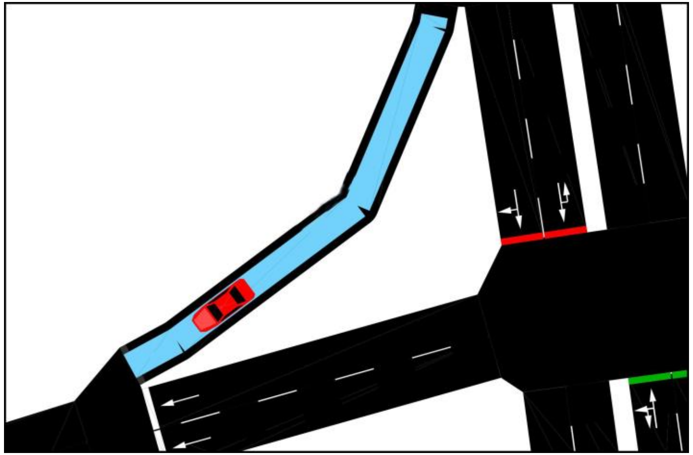
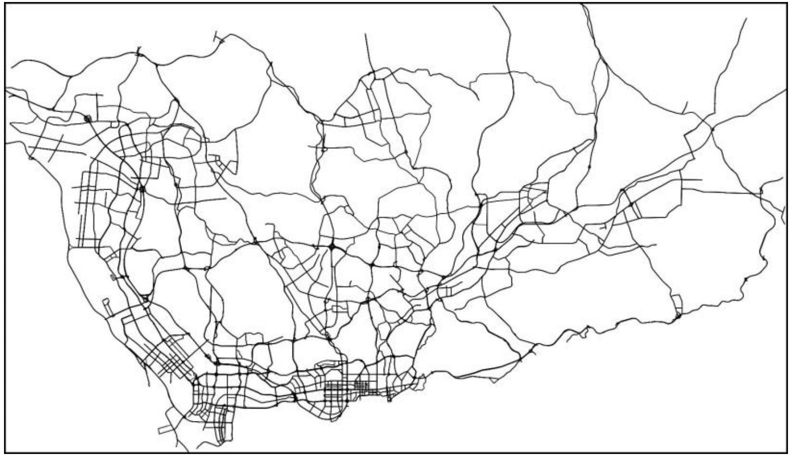
Experiment Setup

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.

Parameters	Setting
Charging rate C	150 kW
Charger unit price ω_0	\$2,000
Air drag coefficient c_w	0.3
Rolling resistance coefficient c_e	0.01
Mass of a taxicab κ	2,020 kg
Gravity acceleration g	9.8 m/s^2
Battery capacity of a taxicab E_0	75 kWh
SoC threshold η	20%
Vacant SoC threshold θ	80%
Maximum speed limit v_{max}	60 mph

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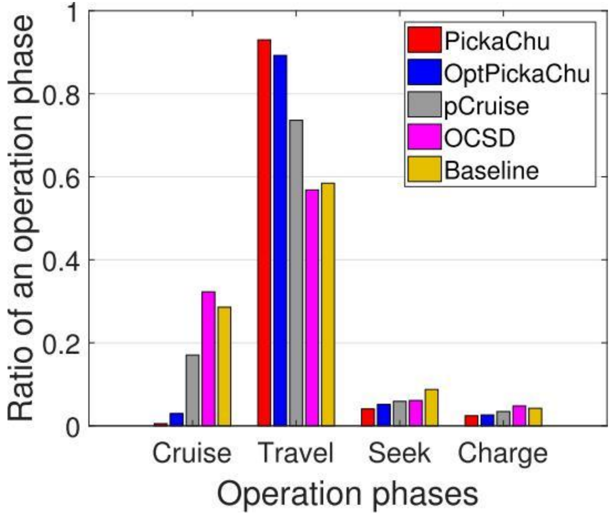
- Use SUMO to simulate 1,000 taxicabs on road network for 24 hours.
- Actual passengers' requests happened on July 15, 2015.

Experiment Results

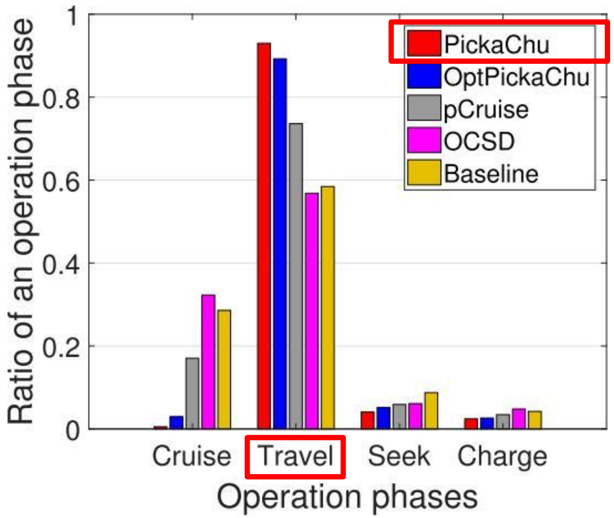
Ratio of the time of each operation phase



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%)



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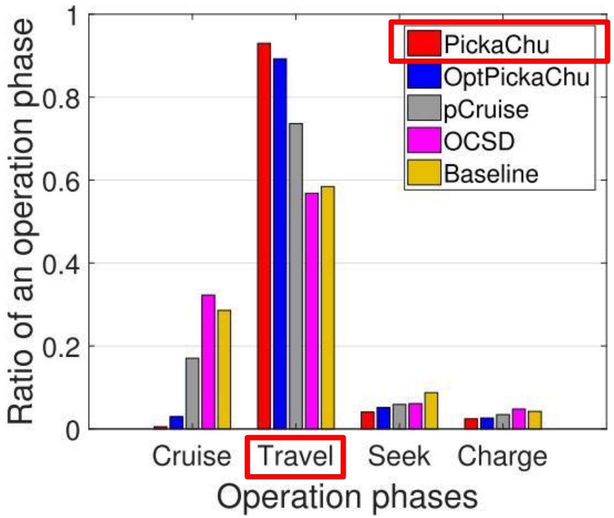

For more details:

Yan L, Shen H, Li Z, Sarker A, Stankovic J.A., Qiu C, Zhao J, Xu C. Employing Opportunistic Charging for Electric Taxicabs to Reduce Idle Time. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*. 2018 Mar 26;2(1):47.

Conclusion

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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