Iowa State University

Modeling the Operations of Electric Autonomous Taxis in New York City

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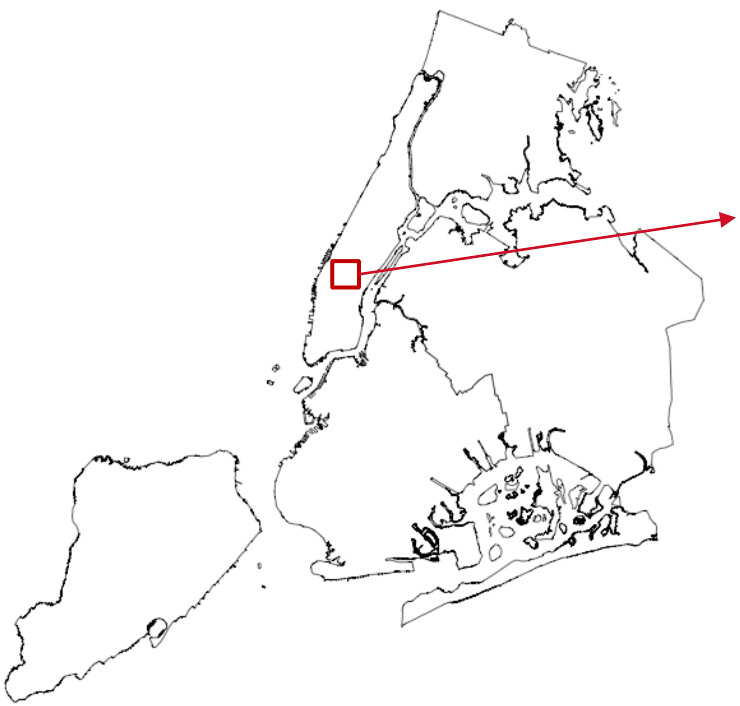
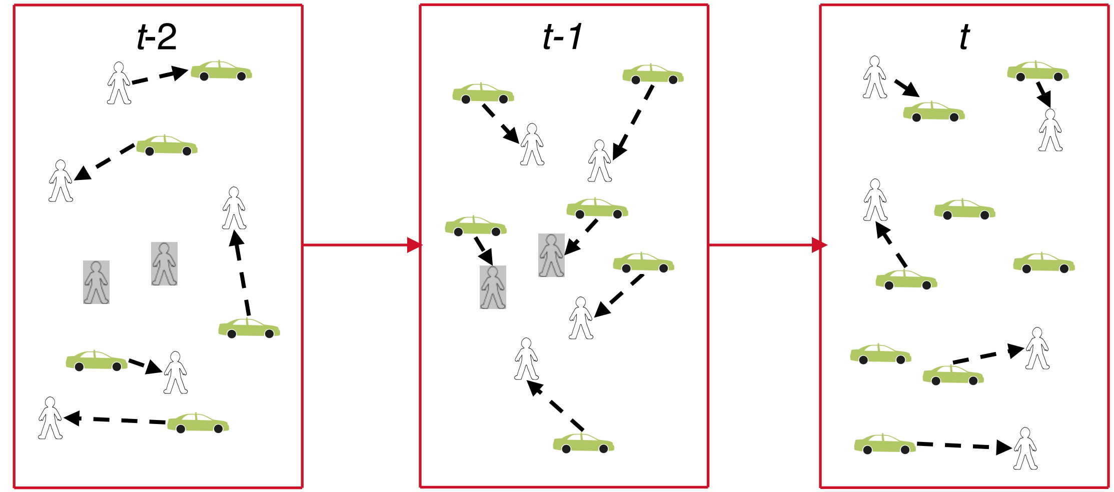
Why Electric Autonomous Taxis?

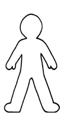
	Conventional taxis	Ride-hailing	Electric autonomous vehicles (EAV)
Energy source	• gasoline • some electric	• gasoline • some electric	• electric
Search for customers	• cruising • by chance	• cruising + waiting • drivers compete	• relocating + waiting • collaborative
Customers' delay	• unknown to taxis	• drivers do not care	• optimal dispatch • reduce delay
Trip distance	• unknown to taxis	• unknown to taxis	• taxis w/o sufficient range are not assigned

Model EAV Taxi Operations





Model operations based on status of both requests and taxis, over time, area by area



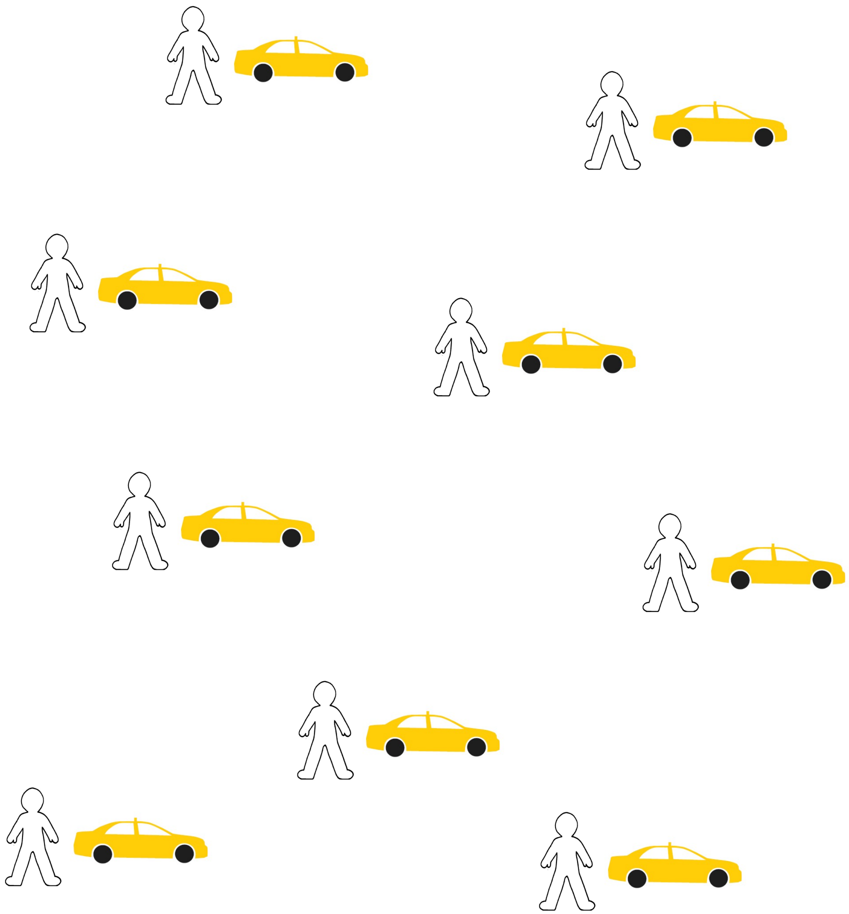
Requests

- request time
- location
- wait time

EAV taxis

- location
- SOC

Taxi Trip Data in NYC



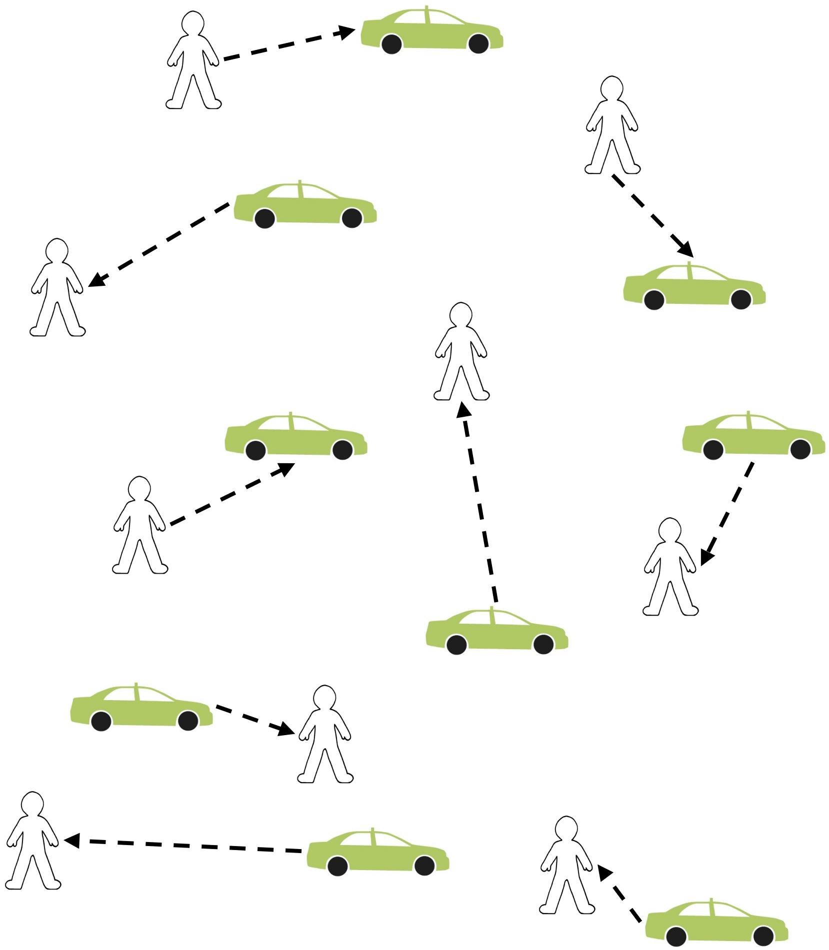
- Data fields
  - taxi ID
  - pick-up GPS
  - pick-up timestamp
  - drop-off GPS
  - drop-off timestamp
  - occupied trip distance

- Estimate empty trip dist. by

  trip dist. = 1.4413 $\times$ straight-line dist. + 0.1383 (unit: mi)

- Extract data of 500 taxis & the corresponding requests

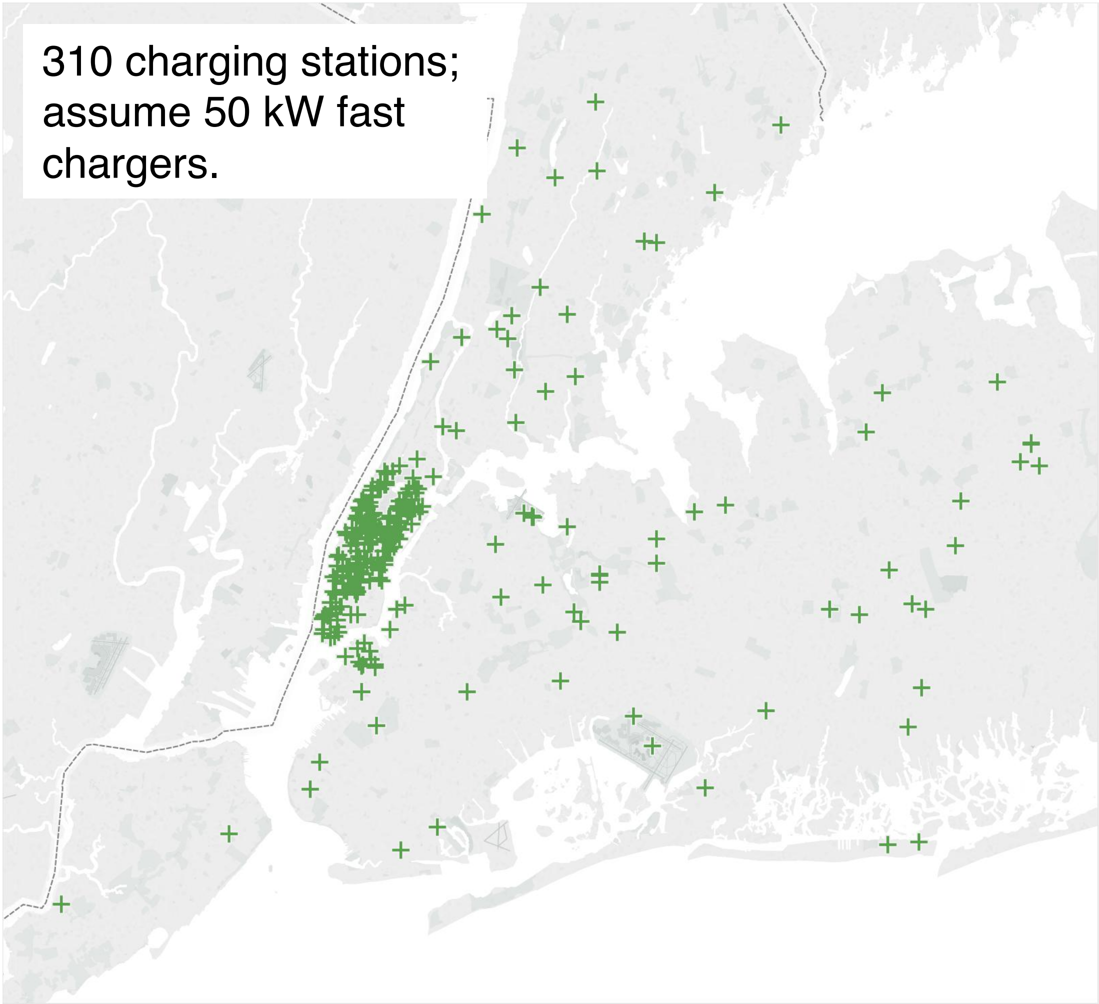
Assumptions for Simulation



- ❑ Requests of customers
  - location: pick-up GPS
  - time: pick-up timestamp
  - dist.: occupied trip dist.

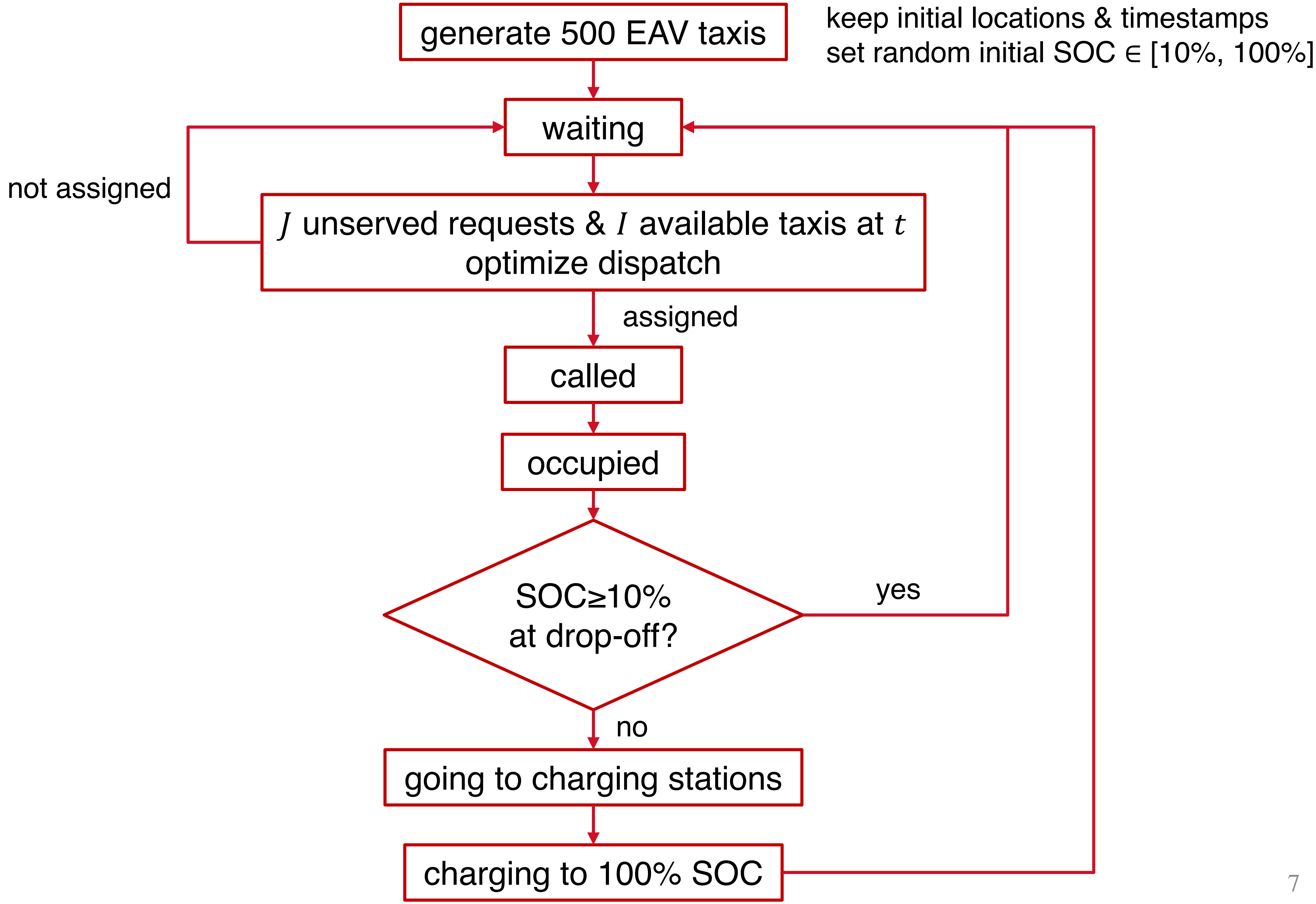
- ❑ EAV taxis
  - location: drop-off GPS
  - time: drop-off timestamp
  - dist.: estimated trip dist.

Charging Stations in NYC



Source: US DOE

Simulation Process



Decision Variables

I available taxis and J unserved requests at t

Define binary decision variables

$$x_{i,j}$$

i: index of an available taxi, $i \in I$

j: index of an unserved request,j $\in J$

$x_{i,j} = 1$: taxi i picks up request j

$x_{i,j} = 0$: taxi i does not pick up request j

Objective Function

$$\text{minimize} \quad \underbrace{\sum_{i=1}^{I}\sum_{j=1}^{J} D_{i,j}^{(1)} x_{i,j}}_{\text{total costs of the requests that can be served}} + \underbrace{\sum_{j=1}^{J} D_{j}^{(2)} \left(1 - \sum_{i=1}^{I} x_{i,j}\right)}_{\text{total costs of the requests that cannot be served}}$$

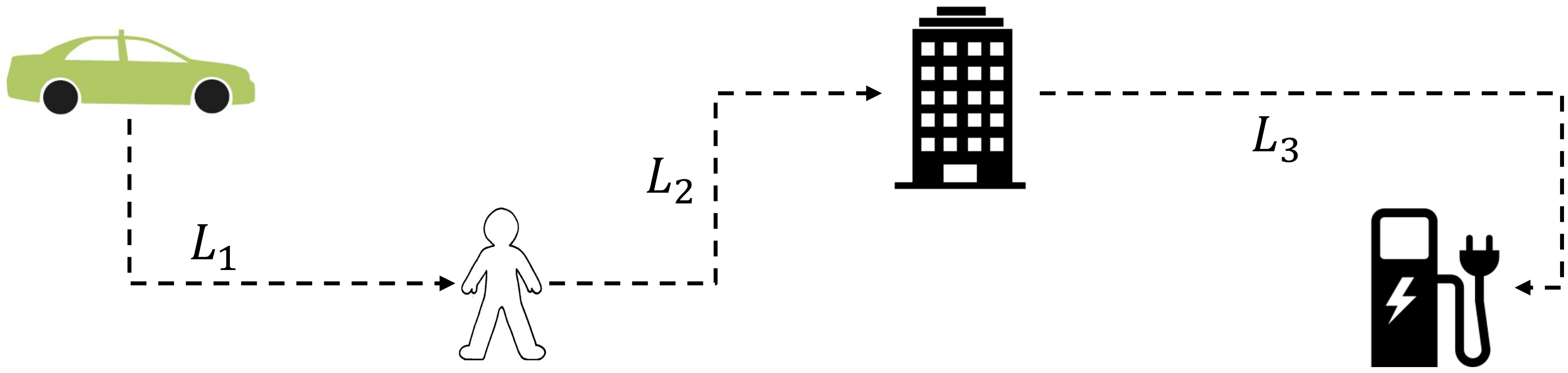
$D_{i,j}^{(1)}$: cost matrix (1) = time that has been delayed + time for pick-up

$D_{j}^{(2)}$: cost matrix (2) = time that has been delayed + avg. wait time

differs by area

Constraints (1): Sufficient EV Range

- calculate the distance matrix $L_{I\times J} = L_1 + L_2 + L_3$



- if $L_{i,j}$ > the taxi's remaining range,

$$x_{i,j} = 0$$

Constraints (2)

- Each taxi will server at most one customer

$$\sum_{j=1}^{J} x_{i,j} \leq 1, \forall I$$

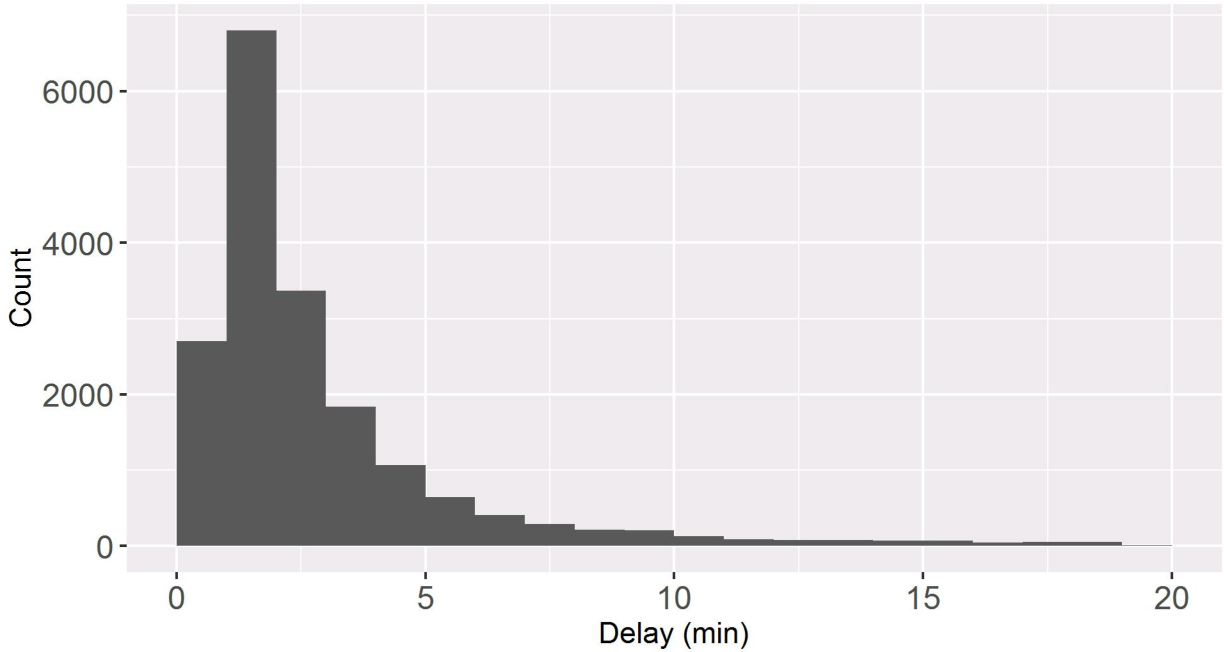
- Each customer will be served by at most one taxi

$$\sum_{i=1}^{I} x_{i,j} \leq 1, \forall J$$

Solver

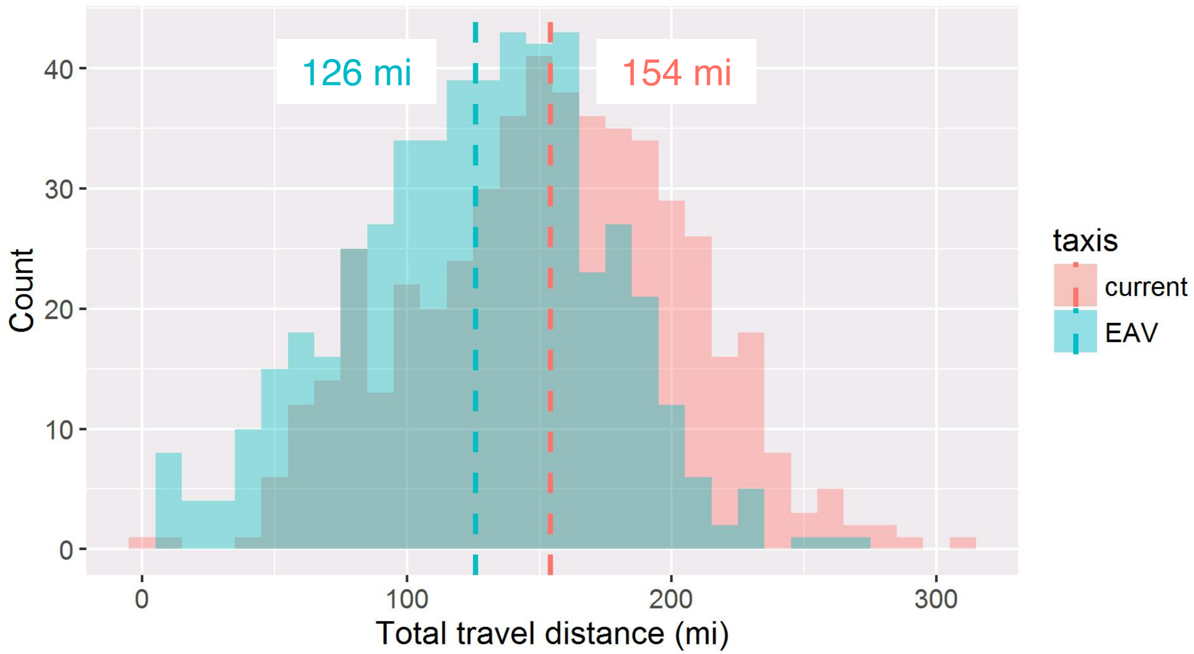
- Gurobi 7.5.1
- integer linear programming (ILP)
- 1440 time intervals
- CPU Intel E5-1620 3.70GHz, RAM 16GB
- ~40 minutes

Customer Wait Time Distribution



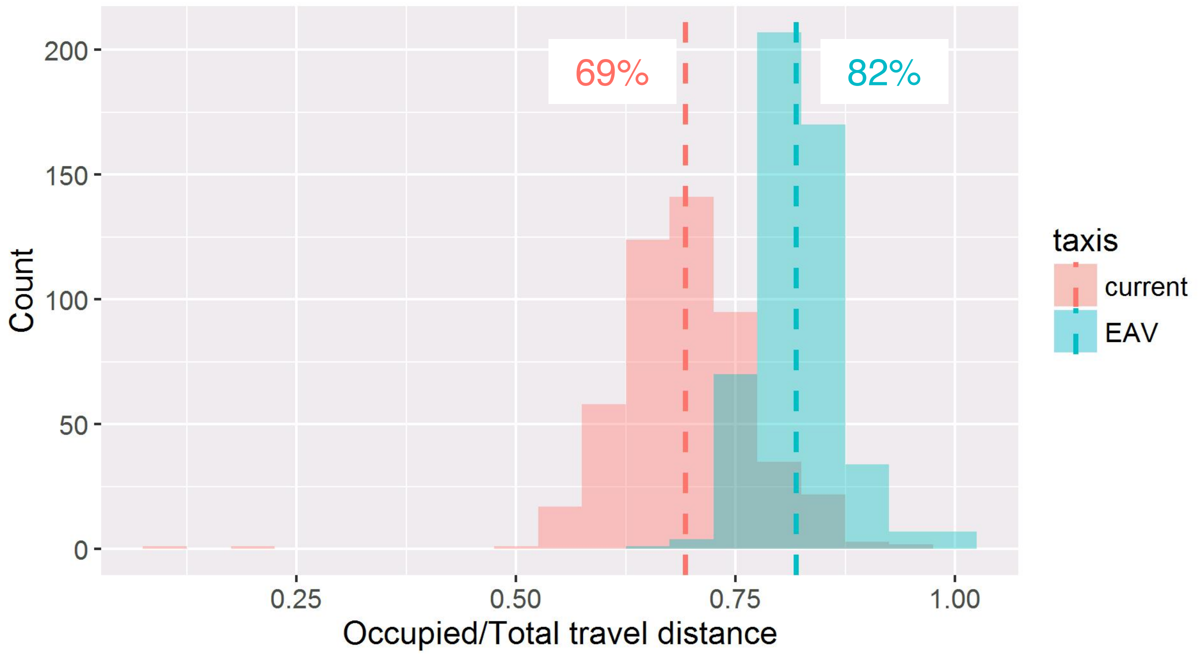
- Only 0.5% of requests are not served
- Average wait time is 4.7 minutes
- 95% of requests are served within 11 minutes

Total Travel Distance of Taxis



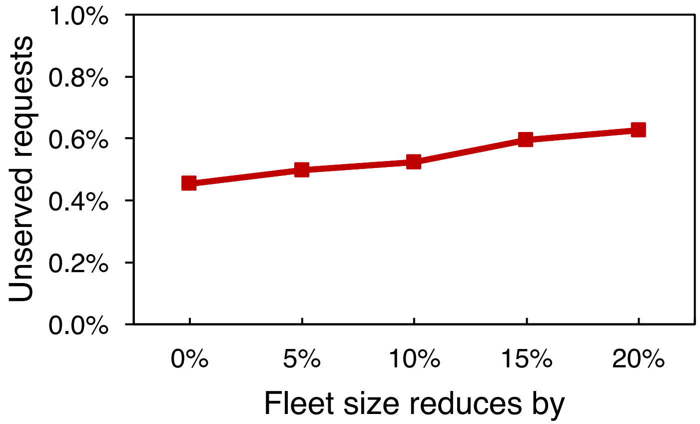
- Average travel distance reduces by 18%

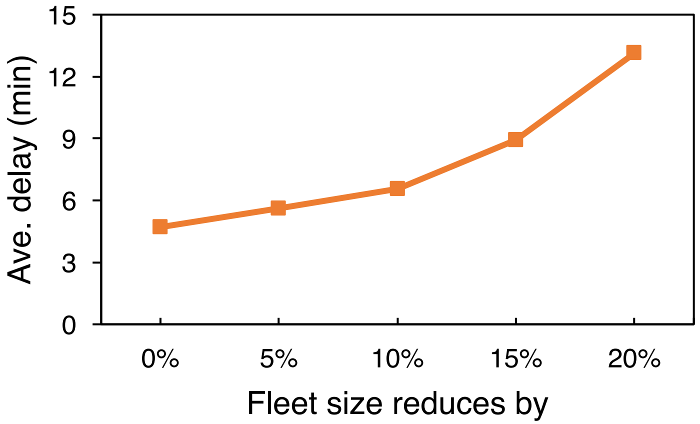
Ratio of Occupied/Total Travel Distance



- EAV taxi system reduces empty trip distance from 49 mi to 23 mi
- Average ratio of occupied distance increases from 69% to 82%

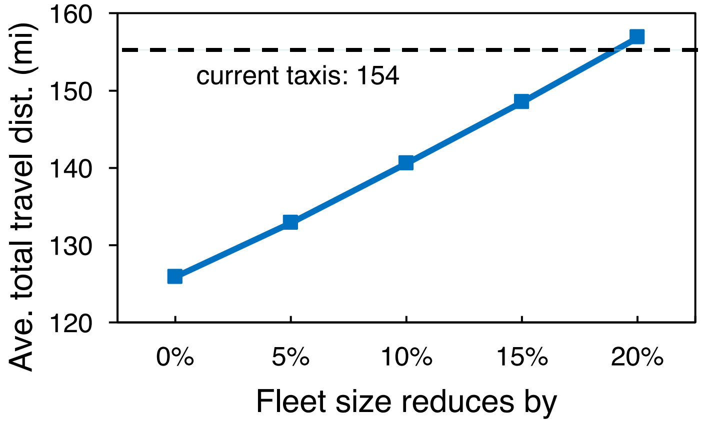
Implications of Fleet Size

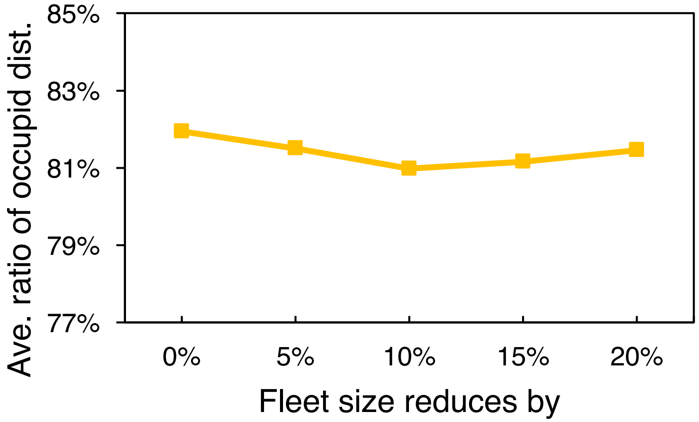


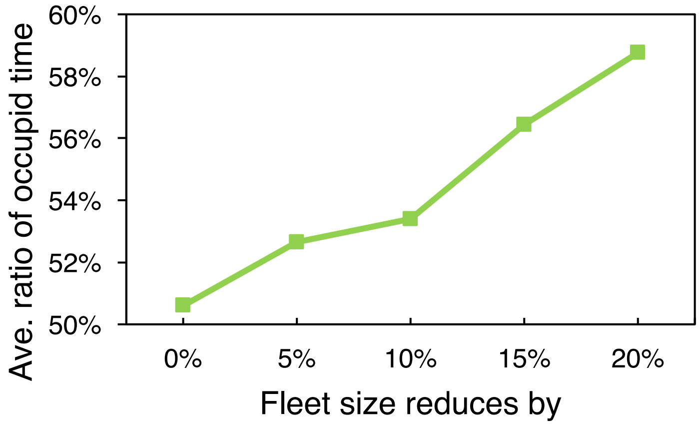


- Reduces fleet size by 5%~20%
- Unserved requests remain at 0.5%~0.6%
- Average delay is within 9 minutes when fleet size reduces by ≤15%
- Average delay increases more significantly at 20% reduction

Implications of Fleet Size

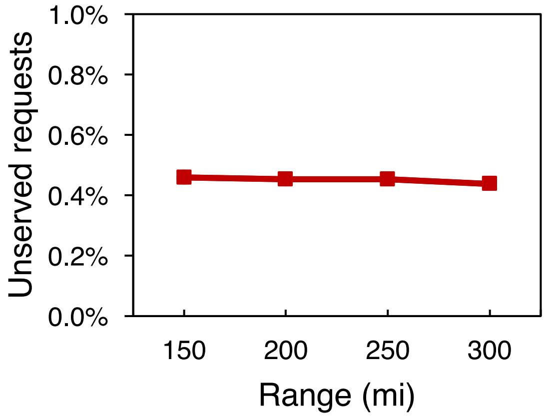




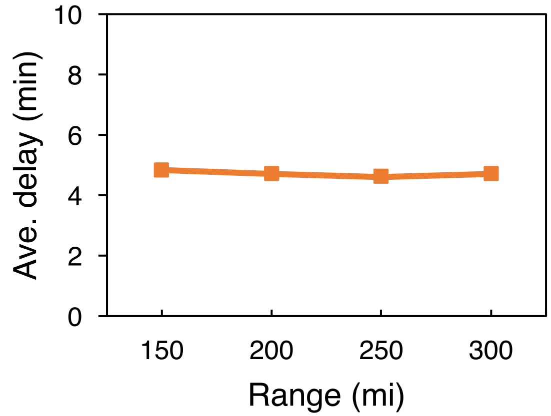


- With smaller fleet size, EAV taxis become busier
  - travel distance & ratio of occupied time increase almost linearly
- Efficiency of current taxi system ≈ EAV taxis with 80% of fleet size
- Ratio of occupied distance remains stable at 81%~82%

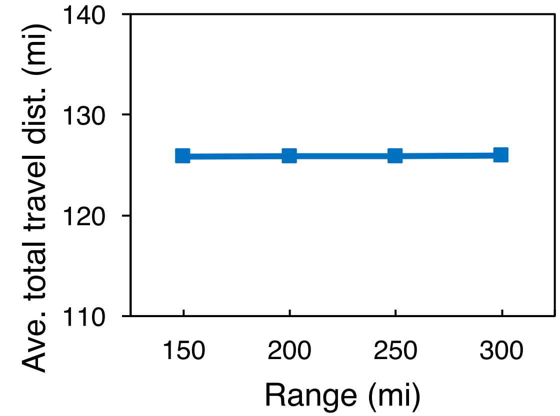
Implications of Electric Range



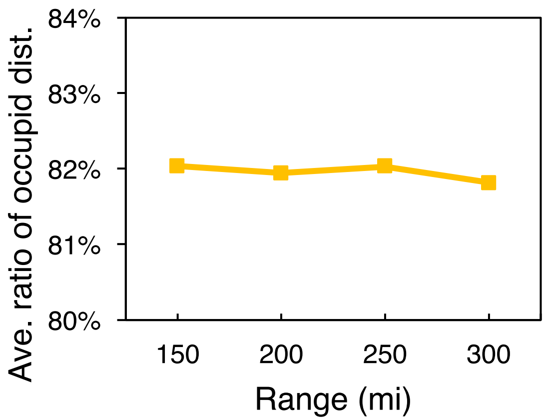
unserved requests: 0.5%



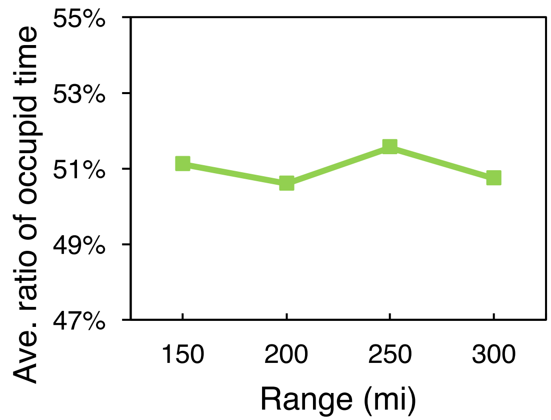
avg. delay: 4.6~4.8 min



avg. total travel dist.: 126 mi



avg. ratio of occupied dist.: 82%



avg. ratio of occupied time: 51%~52%

- Range does not have considerable implications on request delays nor efficiency of EAV taxi systems

Summary

- EAV taxis improves efficiency of taxi systems
  - less empty trips
  - less energy consumption

- EAV taxis has potential to reduce fleet size, while keep wait time at an acceptable level
  - average delay is within 9 min when the fleet size is reduced by 15%

Thank you

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