Ride Substitution Using Electric Bike Sharing: Feasibility, Cost, and Carbon Analysis

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Background and problem

- Ride sharing originally came with the promise of reduced traffic and carbon emissions by reducing reliance on privately owned cars
- However, it has resulted in increased traffic
  - E.g., 50% of all traffic in NYC is made up of ride sharing [1]
- Ride sharing is also 47% more carbon intensive than personal car trips
  - This is mainly due to dead miles [2,3]

1. https://www.citylab.com/transportation/2019/08/uber-lyft-traffic-congestion-ride-hailing-cities-drivers-vmt/595393/
2. https://www.reuters.com/article/us-uber-emissions/ride-hailing-increases-emissions-contributes-to-climate-pollution-study-idUSKBN20J27K
3. https://www.ucsusa.org/resources/ride-hailing-climate-risks

Electric bikes: a greener alternative

- Electric bikes provide pedal assist to the rider using an inbuilt motor and battery
  - This makes biking nearly effortless & ideal for longer rides or uphill rides
- Since most taxi trips are short, they can easily be taken using electric bikes which offer a greener alternative
- This could reduce carbon emission

Research question

What are the costs and carbon benefits of encouraging more bike sharing as a substitute for shorter ride sharing trips? What is the feasibility of such an approach?

Overview of datasets

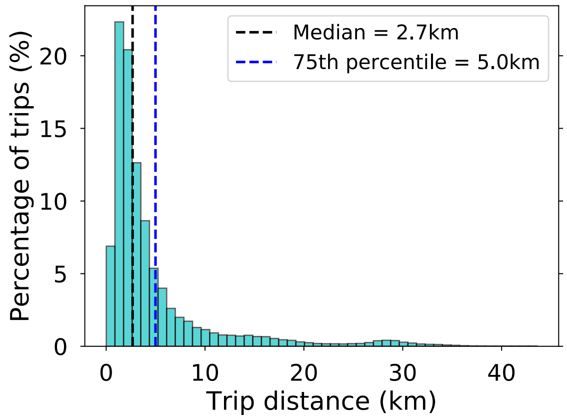
- To address these questions, we use the following open datasets

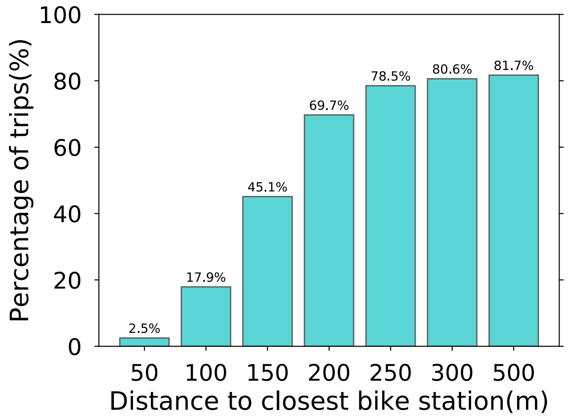
CitiBike	
# of bikes	18K
# of trips	19M
# of stations	941
Duration	Jul 2018 – Jun 2019

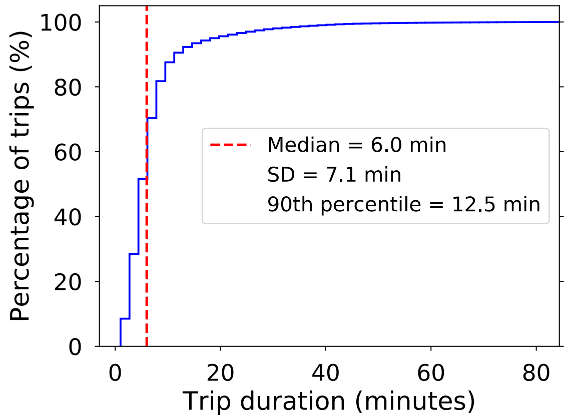
Taxi	
# of vehicles	22K
# of trips	101M
Type	Yellow, Green
Duration	Jul 2018 – Jun 2019

For Hire Vehicles	
# of vehicles	78K
# of trips	253M
Type	Uber, Lyft, Via, Juno
Duration	Jul 2018 – Jun 2019

Are ride share trips feasibly substitutable by bikes trips?

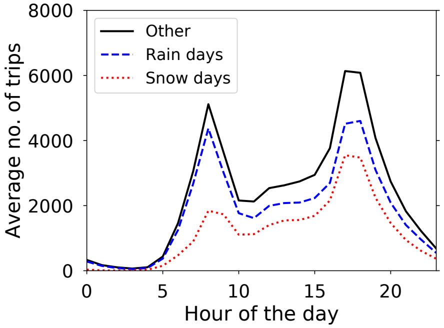


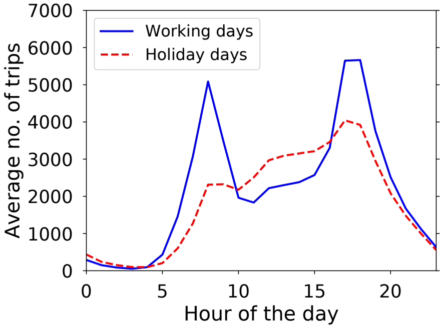


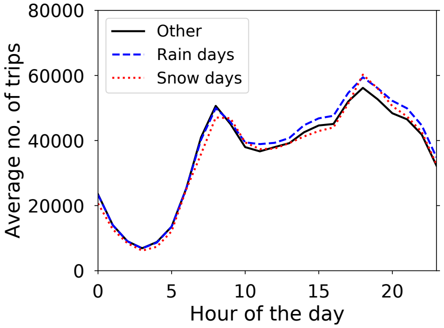


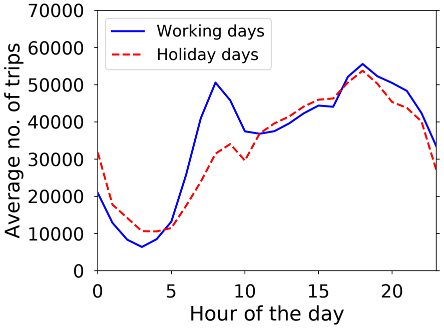
- Feasibility by **distance**: The median taxi trip is quite short (2.7km), which can easily be taken using a bike
- Feasibility by **pickup and drop-off**: Up to 70% of taxi trips are within 200m of a bike station
- **Convenience**: Short bike trips (2km) are *faster* than car trips. Median bike trip takes 6 minutes vs 10 minutes for car rides

Which taxi trips are eligible for substitution?









- Lower demand for bike trips on rainy and snowy days
- Low demand for night trips

- Lower peak demand for bike trips on holidays, but higher demand during day hours

- Higher peak demand for rainy and snowy days
- Higher demand for night trips than bike trips

- Lower peak demand on holiday days
- Higher demand for night trips on holiday days

Ride substitution with regular and electric bikes

- Linear optimization framework
- Minimize number of required bikes while ensuring
  - Trip demand is fully met
  - Short rides are taken using regular bikes
  - Long trips are taken using electric bikes
  - Medium distance trips are taking using either, whichever is available first

Formulation

$\mathcal{S} = \{1, \ldots, n\}$ → Set of stations in a BSS

$x_i(t)$ → Electric bikes at station *i* and time *t*

$y_i(t)$ → Regular bikes at station *i* and time *t*

$I_i^{\mathsf{M,e}}(t)$ → Set of incoming medium trips using electric bikes

$I_i^{\mathsf{M,r}}(t)$ → Set of incoming medium trips using regular bikes

$O_i^{\mathsf{M,e}}(t)$ → Set of outgoing medium trips using electric bikes

$O_i^{\mathsf{M,r}}(t)$ → Set of outgoing medium trips using regular bikes

Formulation (continued)

$$\min \quad \sum_{i=1}^{n} x_i(1) + y_i(1)$$

Demand constraints

$$I_i(t) = I_i^{\mathsf{L}}(t) + I_i^{\mathsf{S}}(t) + I_i^{\mathsf{M}}(t), \quad \forall i, \forall t.$$

$$O_i(t) = O_i^{\mathsf{L}}(t) + O_i^{\mathsf{S}}(t) + O_i^{\mathsf{M}}(t), \quad \forall i, \forall t.$$

$$I_i(t) + x_i(t) + y_i(t) \geq O_i(t), \quad \forall i, \forall t.$$

$$I_i^{\mathsf{L}}(t) + I_i^{\mathsf{M,e}}(t) + x_i(t) \geq O_i^{\mathsf{L}}(t) + O_i^{\mathsf{M,e}}(t), \quad \forall i, \forall t,$$

$$I_i^{\mathsf{S}}(t) + I_i^{\mathsf{M,r}}(t) + y_i(t), \geq O_i^{\mathsf{S}}(t) + O_i^{\mathsf{M,r}}(t), \quad \forall i, \forall t.$$

$$I_i^{\mathsf{M}}(t) = I_i^{\mathsf{M,e}}(t) + I_i^{\mathsf{M,r}}(t), \quad \forall i, \forall t,$$

$$O_i^{\mathsf{M}}(t) = O_i^{\mathsf{M,e}}(t) + O_i^{\mathsf{M,r}}(t), \quad \forall i, \forall t.$$

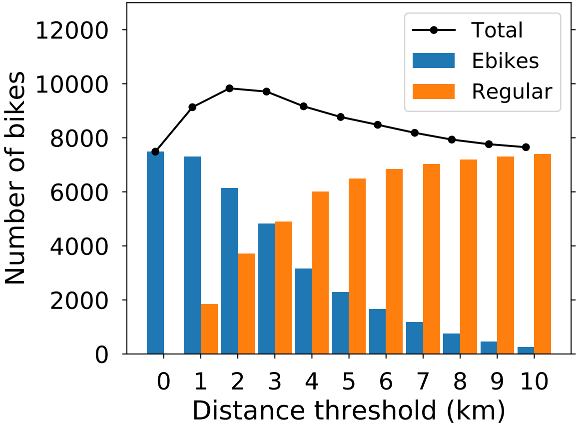
Flow conservation

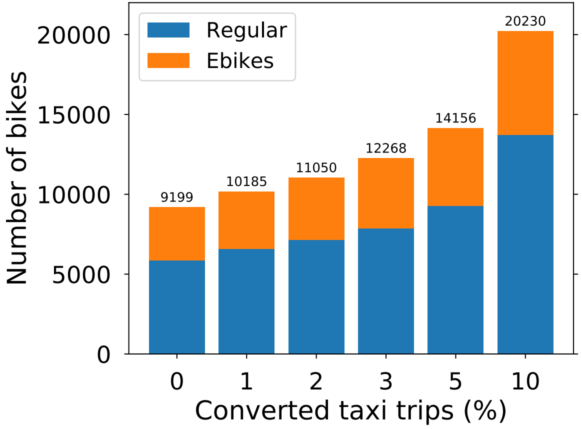
$$x_i(t+1) + y_i(t+1) = x_i(t) + y_i(t) + I_i(t) - O_i(t), \quad \forall i, \forall t.$$

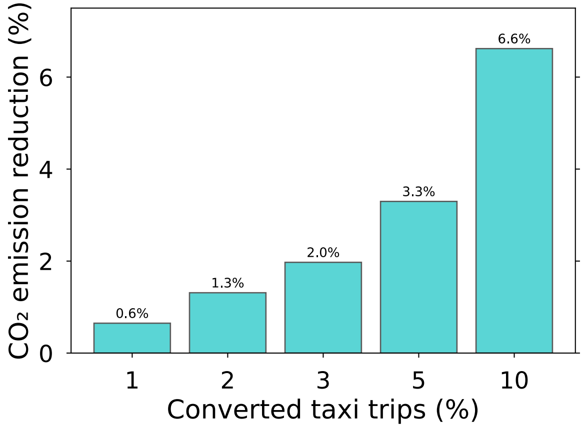
$$x_i(t+1) = I_i^{\mathsf{L}}(t) + I_i^{\mathsf{M,e}}(t) + x_i(t) - O_i^{\mathsf{L}}(t) - O_i^{\mathsf{M,e}}(t), \quad \forall i, \forall t,$$

$$y_i(t+1) = I_i^{\mathsf{S}}(t) + I_i^{\mathsf{M,r}}(t) + y_i(t) - O_i^{\mathsf{S}}(t) - O_i^{\mathsf{M,e}}(t), \quad \forall i, \forall t.$$

Optimal number of bikes required for substitution

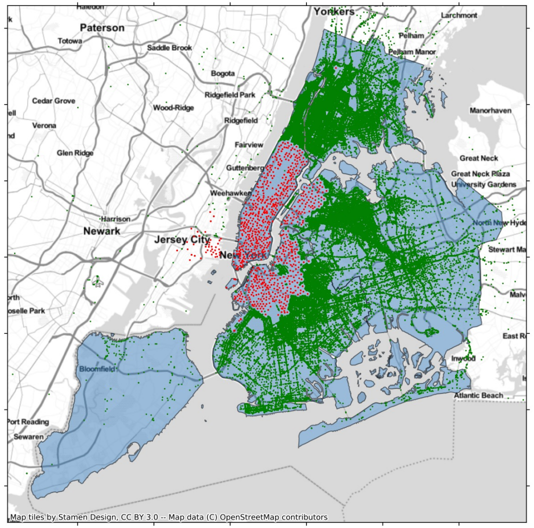


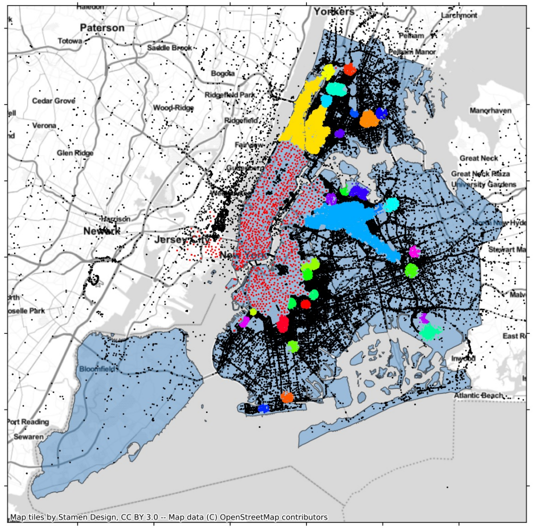




- A hybrid system requires ~30% more bikes but provides more convenience
- Doubling the number of trips leads to a 52% increase in bikes, a sub-linear increase with increased substitution
- Up to 6.6% of total carbon emission (2100MT) can be eliminated with 10% trip substitution

Expanding an existing bike share system





- Red markers – existing bike stations
- Green markers – unclustered taxi trips
- Current bike share coverage is centered in one location

- Multiple colors – Discovered trip clusters
- Black markers – sparse taxi trips
- Clusters form demand for new bike stations

Expanding an existing bike share system

	Current	Expanded	% Change
Stations	941	1761	87%
Bikes	9199	12310	33.8%
CO_2 (MT)	183,648	168,835	-8%

- Expansion incurs a higher investment cost. This is reasonable, since the geographical area covered is nearly the same
- Nearly double the number of stations are required in the expanded system
- Total annual CO_2 emission can be reduced by up to 8% from such expansion

Summary & Conclusions

- Car rides are easily substitutable with bikes
  - 50% of car rides are < 3.6km long
  - 69% of car rides are within 200m of a bike station
- Number of bikes increases sub-linearly with increase in substituted rides
- There exists opportunity to expand existing bike share systems to take advantage of trip clusters outside of the coverage region
- If implemented, ride substitution can lead to significant carbon reduction

Thank You!