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].

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

<table>
<thead>
<tr>
<th></th>
<th>CitiBike</th>
<th>Taxi</th>
<th>For Hire Vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td># of bikes</td>
<td>18K</td>
<td>22K</td>
<td>78K</td>
</tr>
<tr>
<td># of trips</td>
<td>19M</td>
<td>101M</td>
<td>253M</td>
</tr>
<tr>
<td># of stations</td>
<td>941</td>
<td>Yellow, Green</td>
<td>Uber, Lyft, Via, Juno</td>
</tr>
</tbody>
</table>
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 taken using either, whichever is available first
Formulation

\[ S = \{1, \ldots, n\} \rightarrow \text{Set of stations in a BSS} \]

\[ x_i(t) \rightarrow \text{Electric bikes at station } i \text{ and time } t \]

\[ y_i(t) \rightarrow \text{Regular bikes at station } i \text{ and time } t \]

\[ I^{M,e}_i(t) \rightarrow \text{Set of incoming medium trips using electric bikes} \]

\[ I^{M,r}_i(t) \rightarrow \text{Set of incoming medium trips using regular bikes} \]

\[ O^{M,e}_i(t) \rightarrow \text{Set of outgoing medium trips using electric bikes} \]

\[ O^{M,r}_i(t) \rightarrow \text{Set of outgoing medium trips using regular bikes} \]
Formulation (continued)

\[
\begin{align*}
\text{Demand constraints} \\
I_i(t) &= I_i^e(t) + I_i^s(t) + I_i^m(t), \quad \forall i, \forall t. \\
O_i(t) &= O_i^l(t) + O_i^s(t) + O_i^m(t), \quad \forall i, \forall t. \\
I_i(t) + x_i(t) + y_i(t) &\geq O_i(t), \quad \forall i, \forall t. \\
I_i^e(t) + I_i^m,e(t) + x_i(t) &\geq O_i^l(t) + O_i^m,e(t), \quad \forall i, \forall t. \\
I_i^s(t) + I_i^m,r(t) + y_i(t) &\geq O_i^s(t) + O_i^m,r(t), \quad \forall i, \forall t. \\
I_i^m(t) &= I_i^m,e(t) + I_i^m,r(t), \quad \forall i, \forall t. \\
O_i^m(t) &= O_i^m,e(t) + O_i^m,r(t), \quad \forall i, \forall t.
\end{align*}
\]

\[
\begin{align*}
\text{Flow conservation} \\
x_i(t + 1) + y_i(t + 1) &= x_i(t) + y_i(t) + I_i(t) - O_i(t), \quad \forall i, \forall t. \\
x_i(t + 1) &= I_i^e(t) + I_i^m,e(t) + x_i(t) - O_i^l(t) - O_i^m,e(t), \quad \forall i, \forall t. \\
y_i(t + 1) &= I_i^s(t) + I_i^m,r(t) + y_i(t) - O_i^s(t) - O_i^m,r(t), \quad \forall i, \forall t.
\end{align*}
\]
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
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.

<table>
<thead>
<tr>
<th></th>
<th>Current</th>
<th>Expanded</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stations</td>
<td>941</td>
<td>1761</td>
<td>87%</td>
</tr>
<tr>
<td>Bikes</td>
<td>9199</td>
<td>12310</td>
<td>33.8%</td>
</tr>
<tr>
<td>CO(_2) (MT)</td>
<td>183,648</td>
<td>168,835</td>
<td>-8%</td>
</tr>
</tbody>
</table>
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!