A Cost-Competitiveness Analysis of Charging Infrastructure for Electric Bus Operations

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$^2$Utah State University

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Introduction

Figure: EV Market Share (%)

- limited driving range
- long charging time
- expensive battery
- shortage of charging infrastructure

Zhibin Chen, Yafeng Yin, Ziqi Song
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A Cost-Competitiveness Analysis of Charging Infrastructure

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Charging Lane
- Reduced charging delay and EVs battery size
- High construction cost

Charging Station
- Less construction cost
- Long charging delay

Swapping Station
- Short charging delay
- Additional amount of batteries
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Which one is more economically competitive?
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Objective

- Conduct a cost analysis of different types of charging facilities in a transit system to serve the charging needs of electric buses.

- Identify factors that may have a great impact on the cost competitiveness of different charging infrastructure.

- Assess the cost competitiveness of charging lanes on the worldwide BRT corridors.
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Setting & Assumption

- A single loop bus line is considered.
- Stationary charging infrastructure is only deployed at the bus terminal.
- Charging lanes are uniformly deployed along the bus line.

**Figure:** Bus line with charging stations (left) and charging lanes (right)
Setting & Assumption

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**Figure:** Bus line with charging stations (left) and charging lanes (right)
Setting & Assumption

- All buses are identical and are operated by the same bus company.
- All charging facilities are constructed and operated by the bus company.
- The bus service frequency is fixed.
- The average operating speed of buses, considering dwelling times at bus stations, is constant along the bus line.
- Buses do not need to slow down to recharge on charging lanes.
- The bus company aims to minimize the total capital cost for both the infrastructure and fleet.
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Model

- **Variables**
  - Bus fleet size
  - Battery size
  - Configuration of charging infrastructure:
    - Charging station
      - # chargers
      - # batteries
    - Swapping station
      - # chargers
      - # batteries
    - Charging lane
      - Total length
      - # segments
      - # inverters

- **Constraints**
  - Guaranteeing the service frequency
  - Satisfying the charging need

- **Objective**
  - Infrastructure + Fleet cost
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• Variables
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  • Battery size
  • Configuration of charging infrastructure:
    • charging station
    • swapping station
    • charging lane
  • # chargers
  • # batteries

• Constraints
  • Guaranteeing the service frequency
  • Satisfying the charging need

• Objective is to minimize
  • Infrastructure + Fleet cost
### Tradeoff

<table>
<thead>
<tr>
<th></th>
<th>Charging Station</th>
<th>Swapping Station</th>
<th>Charging Lane</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Charging Delay</strong></td>
<td>Large</td>
<td>Medium</td>
<td>0</td>
</tr>
<tr>
<td><strong>Fleet Size</strong></td>
<td>Large</td>
<td>Medium</td>
<td>Small</td>
</tr>
<tr>
<td><strong>Battery Size</strong></td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td><strong>Infrastructure Cost</strong></td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Infrastructure Parameter</td>
<td>Value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------------------------------------------------------------</td>
<td>------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recharging efficiency for charging or swapping stations</td>
<td>0.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recharging efficiency for charging lanes</td>
<td>0.85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>State of charge range (SOCR)</td>
<td>0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electric power of charging or swapping station</td>
<td>120 kW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electric power of charging lane</td>
<td>80 kW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fixed construction area for each charging station</td>
<td>2,000 ft²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construction area required for one charger</td>
<td>900 ft²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unit construction cost</td>
<td>$104/ft²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Installation cost per unit of charging power</td>
<td>$444/kW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unit manufacturing cost for battery</td>
<td>$570/kWh</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unit manufacturing cost for bus (excluding battery)</td>
<td>$315,320/veh</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construction cost for battery swapping system without chargers</td>
<td>$562,400</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construction cost for building one mile of charging lane</td>
<td>$321,800/mi</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inverter cost per unit of charging power</td>
<td>$250/kW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fixed cost of constructing power transmitter</td>
<td>$20,000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The nominal scenario is based on the Metro Orange Line, a bus rapid transit (BRT) corridor in Los Angeles.

<table>
<thead>
<tr>
<th>Bus Line Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service frequency</td>
<td>16 veh/h</td>
</tr>
<tr>
<td>Operating hours</td>
<td>22.2 h</td>
</tr>
<tr>
<td>Circulation length</td>
<td>35.2 mi</td>
</tr>
<tr>
<td>Average speed</td>
<td>19.9 mph</td>
</tr>
</tbody>
</table>
Figure: Results in the nominal scenario
Sensitivity Analysis

Figure: Sensitivity analysis
Sensitivity Analysis

Figure: Competitive domain of charging infrastructure
Sensitivity Analysis

Figure: Sensitivity analysis of charging-lane parameters
## Empirical Analysis

### A Cost-Competitiveness Analysis of Charging Infrastructure

#### BRT Corridors

<table>
<thead>
<tr>
<th>City</th>
<th>Circulation Length (mi)</th>
<th>Service Frequency (veh/h)</th>
<th>Operating Speed (mph)</th>
<th>Competitive Infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amsterdam</td>
<td>55.3</td>
<td>18</td>
<td>21.1</td>
<td>Swapping Station</td>
</tr>
<tr>
<td>Bangkok</td>
<td>8.2</td>
<td>15</td>
<td>16.2</td>
<td>Charging Lane</td>
</tr>
<tr>
<td>Beijing</td>
<td>73.3</td>
<td>30</td>
<td>11.8</td>
<td>Charging Lane</td>
</tr>
<tr>
<td>Bogota</td>
<td>130.5</td>
<td>312</td>
<td>14.3</td>
<td>Charging Lane</td>
</tr>
<tr>
<td>Brisbane</td>
<td>33.9</td>
<td>232</td>
<td>15.5</td>
<td>Charging Lane</td>
</tr>
<tr>
<td>Buenos Aires</td>
<td>79.7</td>
<td>193</td>
<td>11.5</td>
<td>Charging Lane</td>
</tr>
<tr>
<td>Cali</td>
<td>42.3</td>
<td>164</td>
<td>9.0</td>
<td>Charging Lane</td>
</tr>
<tr>
<td>Changde</td>
<td>23.5</td>
<td>27</td>
<td>19.3</td>
<td>Charging Lane</td>
</tr>
<tr>
<td>Changzhou</td>
<td>64.5</td>
<td>43</td>
<td>10.6</td>
<td>Charging Lane</td>
</tr>
<tr>
<td>Chengdu</td>
<td>35.8</td>
<td>101</td>
<td>18.6</td>
<td>Charging Lane</td>
</tr>
<tr>
<td>Dalian</td>
<td>11.2</td>
<td>86</td>
<td>12.0</td>
<td>Charging Lane</td>
</tr>
<tr>
<td>Guangzhou</td>
<td>28.0</td>
<td>320</td>
<td>11.2</td>
<td>Charging Lane</td>
</tr>
<tr>
<td>Hangzhou</td>
<td>35.3</td>
<td>67</td>
<td>7.6</td>
<td>Charging Lane</td>
</tr>
<tr>
<td>Hefei</td>
<td>8.9</td>
<td>80</td>
<td>10.6</td>
<td>Charging Lane</td>
</tr>
<tr>
<td>Istanbul</td>
<td>60.8</td>
<td>137</td>
<td>21.7</td>
<td>Charging Lane</td>
</tr>
<tr>
<td>Jakarta</td>
<td>166.5</td>
<td>40</td>
<td>12.4</td>
<td>Charging Lane</td>
</tr>
<tr>
<td>Jinan</td>
<td>51.7</td>
<td>49</td>
<td>10.9</td>
<td>Charging Lane</td>
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<tr>
<td>Kuala Lumpur</td>
<td>6.6</td>
<td>16</td>
<td>13.1</td>
<td>Charging Lane</td>
</tr>
<tr>
<td>Lanzhou</td>
<td>10.7</td>
<td>90</td>
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### BRT Corridors

**Table:** BRT corridors and their corresponding competitive charging infrastructure

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**Finding**

- **The service frequency, circulation length**, and **operating speed** of a transit system are discovered to have a great impact on the cost competitiveness of different charging infrastructure.

- Charging lanes supported by the current inductive CWD technology are **cost competitive** for most of the existing BRT corridors, and their superiority becomes more remarkable for the transit systems with **high service frequency** and **low operating speed**.

- Upgrading the **charging power** and reducing the **unit-length construction cost** for charging lanes show great promise on making charging lanes more cost competitive for transit systems with low service frequency.
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Lab for Innovative Mobility Systems (LIMOS)

- **Economic Analysis**

- **Operational Planning**
Thank You!