A Corridor-Centric Approach to Planning Electric Vehicle Charging Infrastructure

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Introduction

• Why to switch from conventional vehicles?
• Why to switch to electric vehicles?
• Future of electric vehicles fleet
• Batteries and charging station specifications
Design Model

\[
\min z(P, E) = (C_p + P \lambda l \min(1, f) C_s) \left( \frac{l}{\beta \theta E} - 1 \right) + \lambda l C_e E
\]

Subject to:

\[
\left( \frac{l}{\beta \theta E} - 1 \right) \frac{\alpha \theta E}{P} \leq T_0
\]
Special Cases

Discrete capacity for Charging Facility

\[ \min z(P, E) = (C_p + P\lambda l \min(1, f) C_s) \left( \frac{l}{\beta \theta E} - 1 \right) + \lambda l C_e E \]

Subject to: \[ \frac{l}{\beta \theta} - \frac{T_0 P}{\alpha \theta} \leq E \leq \frac{l}{\beta \theta} \]

Battery Swapping

\[ \min z(P, E) = (C'_p + rP_3 \lambda l \min(1, f) C_s) \left( \frac{l}{\beta \theta E} - 1 \right) + n_b C_e E \]

Subject to: \[ \frac{l}{\beta \theta} \left( \frac{T_0}{T_e} + 1 \right) \leq E \leq \frac{l}{\beta \theta} \]

\[ n_b \equiv \lambda l + \left( \frac{l}{\beta \theta E} - 1 \right) \lambda l f \]
Case Study

- Chicago, IL - Madison, WI
- 150 miles
- 80% confident range
## Case Study

**Baseline model**

<table>
<thead>
<tr>
<th>Level service of 100δ</th>
<th>Total travel time (hr)</th>
<th>Energy (kwh)</th>
<th>$E$</th>
<th>Battery range (mile)</th>
<th>Charging Power (kW)</th>
<th>Number of charging stations $m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>2.7</td>
<td>75.0</td>
<td></td>
<td>187.50</td>
<td>0</td>
<td>0</td>
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<tr>
<td>5%</td>
<td>2.9</td>
<td>37.5</td>
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<td>93.75</td>
<td>286.0</td>
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<tr>
<td>15%</td>
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<td>37.5</td>
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<td>93.75</td>
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<td>25%</td>
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<td>62.50</td>
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<td>46.87</td>
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<td>3</td>
</tr>
<tr>
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<td>18.7</td>
<td></td>
<td>46.87</td>
<td>21.4</td>
<td>3</td>
</tr>
</tbody>
</table>
Case Study

Sensitivity of Demand (Baseline model)

- Total cost increases with density and decreases with LOS
- Density is only effective when low
- Increases in delay causes smaller batteries and charging stations with more charging stations
Case Study

Sensitivity of Technology (Baseline model)

- Total cost decreases with the two costs
- Advancing battery technology more effective
- Charging station cost is ineffective when battery cost is low
- Larger batteries are feasible with lower battery cost
Case Study

Discrete capacity for Charging Facility

(a) Low Density ($\lambda=0.01$)  
(b) Medium Density ($\lambda=0.5$)  
(c) High Density ($\lambda=100$)
Case Study
Battery Swapping

Total Cost_{Charging Station} - Total Cost_{Battery Swapping}

- At low density the two options are the same
- Swapping is more competitive at high density and high level of service
Conclusion

• Level 2 charging is indeed socially optimal for very low EV market penetrate rates.
• Level 3 charging is needed to achieve a reasonable level of service.
• Advancing battery technology seems to promise larger impacts than the charging technology.
• Battery swapping enables the use of smaller batteries and to achieve higher level of service.
• If existing infrastructure can be remodeled to support battery swapping and charging operations, charging could be a socially optimal solution for modest levels of service.
Thank You

Questions?