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

Charging Station Cost — **Battery Cost**

$$\min\ z(P,E) = \underbrace{\left(C_p + P\lambda l \min(1,f)\, C_s\right)\left(\frac{l}{\beta\theta E} - 1\right)}_{\text{Charging Station Cost}} + \underbrace{\lambda l C_e E}_{\text{Battery Cost}}$$

Subject to:

$$\left(\frac{l}{\beta\theta E} - 1\right)\frac{\alpha\theta E}{P} \le T_0$$

→ **Level of Service Constraint**

Special Cases

Discrete capacity for Charging Facility

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

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

Battery Swapping

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

Subject to: $\frac{\frac{l}{\beta\theta}}{(\frac{T_0}{t_e}+1)} \leq E \leq \frac{l}{\beta\theta}$

$n_b \equiv \lambda l + \left(\frac{l}{\beta\theta E} - 1\right)\lambda l f$

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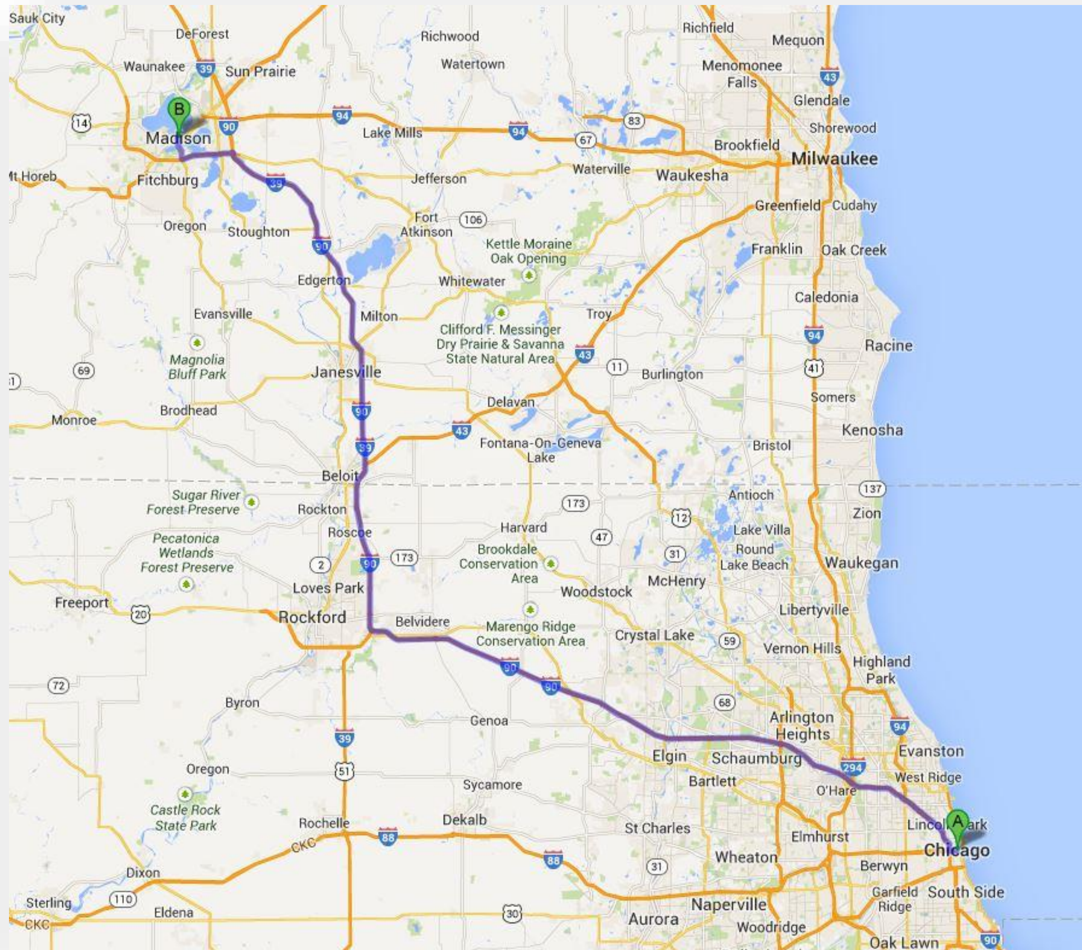
Case Study

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



Case Study

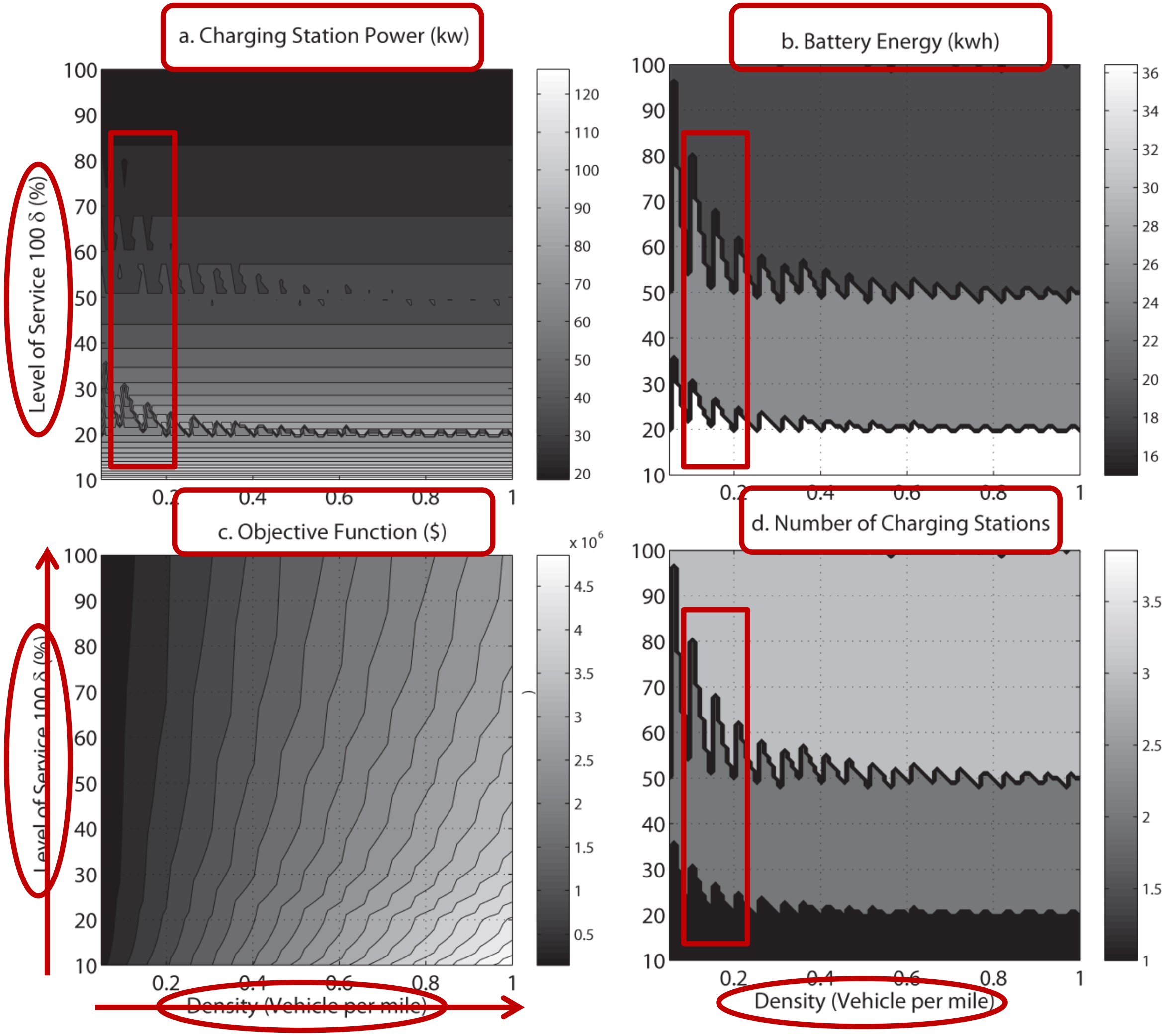
Baseline model

Level of service 100δ	Total travel time (hr)	Energy E (kwh)	Battery range (mile)	Charging Power P (kW)	Number of charging stations m
0%	2.7	75.0	187.50	0	0
5%	2.9	37.5	93.75	286.0	1
15%	3.1	37.5	93.75	95.3	1
25%	3.4	25.0	62.50	76.3	2
50%	4.1	25.0	62.50	38.1	2
85%	5.0	18.7	46.87	25.2	3
100%	5.5	18.7	46.87	21.4	3

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



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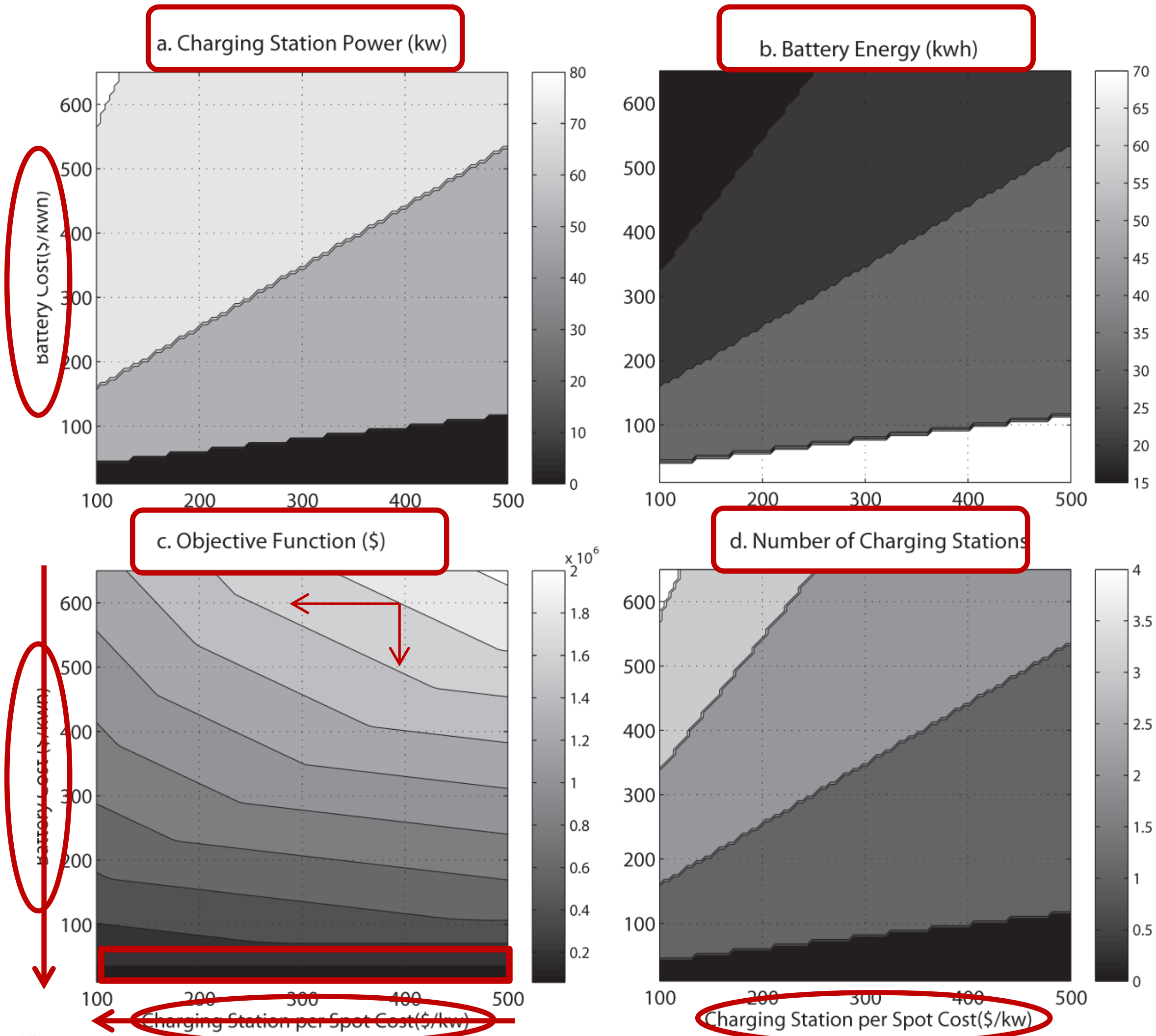
Case Study

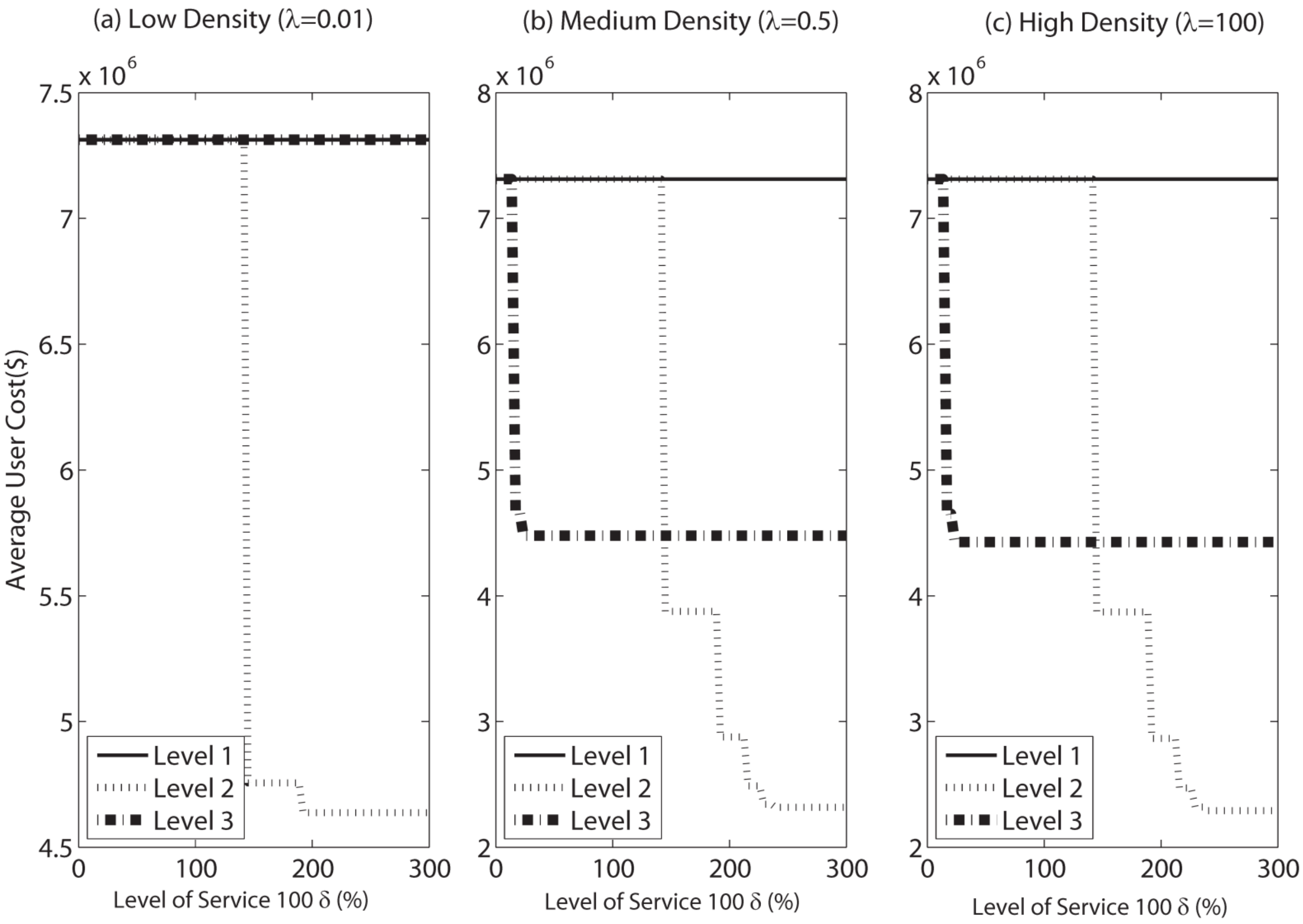
Sensitivity of Technology (Baseline model)

- 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

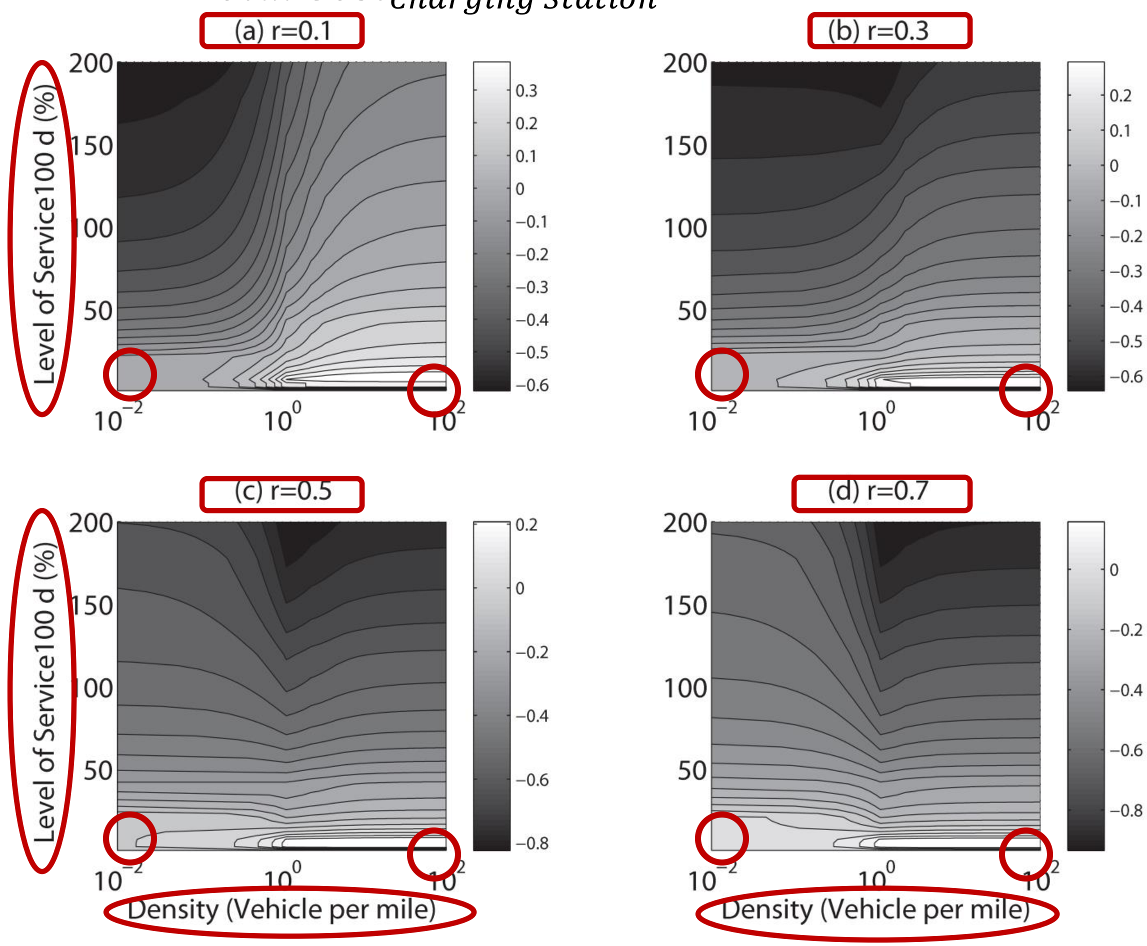


Case Study

Battery Swapping

$$\frac{Total\ Cost_{Charging\ Station} - Total\ Cost_{Battery\ Swapping}}{Total\ Cost_{Charging\ Station}}$$

- 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?