Charging Station Network Design for Electrified Vehicles in Urban Communities: Reducing Congestion, Emissions, Improving Accessibility, and Promoting Walking, Bicycling, and use of Public Transportation

Seyed Sajjad Fazeli, PhD Candidate
Saravanan Venkatachalam, Assistant Professor
Ratna Babu Chinnam, Professor
Alper Murat, Associate Professor
Industrial and Systems Engineering Department
Wayne State University
**Promise** of Electric Vehicles (EV):
- **Diversification** of the transportation energy feedstock
- **Reduction of greenhouse gas** and other emissions
- Improving public health by improving **local air quality**

**Direct and indirect policy incentives** for EV market share growth:
- **Public charger availability** is an indirect policy incentive
  - The most strongly related variable among several socio-economic ones to **EV adoption** (Sierzchula et al., 2014)

**Key decisions** for EV charging network infrastructure:
- Number and location of charging service stations
- Type of charging stations
**US DoT:**

- **Share of vehicles** needing charging can reach **5%**
  - PHEV share would be ~ 2% and BEV ~ 3%
- **3.5% of fleet** projected to be **full EV or PHEV** by 2022-2025
  - California Zero Emission Vehicles (ZEV) program considered in reference case
  - Adoption of ZEV program by nine additional states
Phase I Framework

**OD Pairs based on Household Survey**
- Estimation of potential arrival pattern for parking locations (NHTS) and final destinations

**Driver Behavioral Characteristics**
- Willingness to charge away from home and walking distance preference

**Distribution of final destination of drivers**
- Estimation of dwell time / required hours of charge

**Uncertainty**

**Operational Constraints**
- Pass thru / community traffic and limited parking capacity

**Stochastic Mathematical Model**

**Optimal locations and size of charging stations, and estimation of impact on livability metrics**

*Maximizes accessibility to public EV charging service!*
Research Gap:
- Focus on large-scale state-wide networks and not on urban areas
- Deterministic charging demand
  - Demand is quite stochastic in reality (varying by hour of day, weekday/weekend patterns, commute purpose, destination, etc)

Research Goal:
- Develop a stochastic programming approach to determine location, type of chargers and capacity of charging stations
  - Assess community livability metrics
    - Accessibility to charging service
    - Charging station utilization rate
    - Walkability
  - Account for behaviors of EV drivers
    - Willingness to walk
    - Willingness to pay
    - Willingness to use public charging stations

Assumptions:
- Public parking facilities
- Vehicle parking location
- Vehicle charging time
Setting: Part of Detroit Midtown

- Wide range of employment types (type of final destination) in this area
  - University faculties
  - Offices
  - Hospitals
  - Museums
- Attracts a lot of traffic
- 32 parking lots as potential locations for installing charging stations

EV Market Share: Two Cases

- Conservative: (1%,2%) for (BEV,PHEV)
- Optimistic: (2%,3%) for (BEV,PHEV)
Designing Community-Aware Charging Networks for EVs

- **Two-stage SP** model to determine **location** and **capacity** of public EV charging stations for communities to maximize access
- Incorporation of **uncertainties** (EV demand flows, EV drivers’ charging patterns, arrival and departure time, purpose of arrival to a community, walking preferences)
- Adoption of **SAA** to solve two-stage model
- Effective **heuristic** for **large-scale instances**
- Case study (Detroit midtown area) and post-analysis framework

### Presentations

- Manuscript was accepted in **IEEE Transactions on Intelligent Transportation Systems** (April 2018)
- Presented:
  - INFORMS National Meeting, 2016
Computational Study: Insights

Percentage of accessibility, lost demand and charging utilization in A) (1%,2%) and B) (2%,3%) market shares.

Average hourly utilization in A) weekdays and B) weekends in an optimistic case when \( p=2 \), left, and \( p=6 \), right.
Outline for Phase II

**Choice Modelling for Charger Types**
- Choice modeling approach captures the charging patterns for EV users and will lead to:
  - Accelerating the *adoption* of EVs
  - Better distribution of *budget* to charging infrastructures
  - Increasing the *mobility, accessibility*

**Multi-Modal Transportation for EV Network Design**
- Adding transportation modes (walking, Bicycling, Bus,…) to a network
- Linking transportation networks
  - Link type
  - Node type
Choice Modelling - Framework

Different Level of Chargers (Price, charging time, installation cost)

- Range Charged
- Cost at Home
- Cost at Stop

Derived Interaction Variables

Utility Function

Mathematical Model

Mixed logit Model

Probability of charging

Improving the accessibility

TRCLC Conference | June 21, 2018
- *Wen et al. (2015)* analyzed the charging choices of BEV owners based on a web-based survey in different parts of U.S.

- The choice model computes the volume flowing from demand sources to selected locations, requires to know EV driver preference data, namely the utility of drivers.

\[
P(\text{Charge}) = \frac{e^{U_{it}}}{\sum e^{U_{it}}}
\]

Where \( U_{it} \) is the utility of charging for respondent \( i \) under charging situation \( t \).

- The Choice decision was characterized by the following factors: Charging price, maximum charging power, dwell time, distance to home, current electric range.

- A Mixed Logit Choice Model was used to estimate those factors.
Solution Approach

Mathematical Model

Linearization

Constructing the utility function

Using L-Shape method with callback function

Sensitivity Analysis
Solution Approach: Notation

- **Sets**
  - $J$: Set of parking lots, indexed by $j \in J$
  - $J^* (j)$: Set of parking lots in a specific distance from parking lot $j \in J$
  - $T$: Set of time slots $t \in T$
  - $N$: Set of charging types $n \in N$
  - $A$: Set of all activity types, indexed by $a \in A$
  - $\Gamma$: Set of arrival and departure times, indexed by $\gamma(t) \in \Gamma$ containing time slot $t \in T$
  - $\Omega$: Set of scenarios

- **Number of candidate locations** for installing charging stations

- **Sets**
  - $\delta_j$: Capacity of charging stations $j$

- **Scenario Dependent Parameters**

- **First-Stage Decision Variables**
  - $x_{\delta j}$: 1 if location $j \in J$ is selected for installing charging stations.
  - $z_{\delta n j}$: Number of charging type $n$ in location $j$

- **Second-Stage Decision Variables**
  - $y_{\delta \gamma(t),n,j}(\omega)$: Proportion of demand with arrival and departure time of $\gamma(t) \in \Gamma$ for a given $t \in T$ of charging type $n$ from drivers who are willing to charge their vehicle in parking lot $j$ in scenario $\omega \in \Omega$
Solution Approach: Model (use choice model)

### First-Stage Model

- **$p$ locations for installing charging stations:**
- **Charging capacity in each location:**
- **Feasible set for the binary first-stage variables:**

$$\max f(x,z) = E[\varphi(x,z,\omega)]$$

$$\sum_{j \in J^\uparrow} x_j \leq p$$

$$\sum_{n \in N^\uparrow} z_{n,j} \leq k_j \cdot x_j \quad \forall j \in J$$

$$x_j \in \{0,1\}, z_{n,j} \in \mathbb{Z}, \forall j \in J, n \in N$$

### Second-Stage Model

- **Supply-demand balance:**

$$\varphi(x,z,\omega) = \max \sum_{t \in T, \gamma(t) \in \Gamma, j \in J, n \in N, a \in A^\uparrow} y_{\gamma(t),n,j} (\omega) \cdot d_{\gamma(t), j, a} (\omega) \leq z_{n,j} \quad \forall j \in J$$

- **Choice modeling constraint**

$$y_{\gamma(t),n,j} (\omega) \leq e^{u_j} \cdot y_{\gamma(t),n,a} \cdot z_{n,j} / \sum_{j \in J, n \in N^\uparrow} e^{u_j}$$

- **Demand assignment to parking lots:**

$$\sum_{j \in J^\uparrow} y_{\gamma(t),n,j} (\omega) \leq 1 \quad \forall t \in T, \gamma(t) \in \Gamma, a \in A, n \in N$$

$$y_{\gamma(t),n,j} (\omega) \geq 0 \quad \forall \gamma(t) \in \Gamma, j \in J, t \in T, n \in N$$
Preliminary Results

Configuration 1: only level 3 charger
Configuration 2: only level 2 charger
Configuration 3: All three levels of chargers
Outline for Phase II

Behavioral Model

Strategic plan

- Multi Modal Transportation
  - Quality, Connectivity, Accessibility, Mobility substitutes, Affordability, Demand modeling

Tactical Plan

- EV Charging Network Design
  - State of charge, Arrival pattern, Dwell time, Final destination, Market share penetration, Budget, etc.

- Pricing Scheme
  - Demand/price elasticity, Utilization, Arrival pattern

Drivers’ willingness to walk

Determine optimal locations of charging stations, type, size, estimate livability indices and accessibility

Stochastic network design and flow allocation mathematical model
Multi-Modal Network

An example of multimodal transportation network.

- Walking mode
- Public transit mode
- Auto mode
- EVCS
- Road node
- Metro Stations
Define a Multi-Modal transportation Network

Determine the location and capacity of EV sites to increase the accessibility range to EVs

Determine flow of passengers on every link

Define feasible flow patterns

User’s choice behavior can be captured by a multinomial logit model or equilibrium model

Nodes Type
O-D pairs, EV candidate sites

Links Type
boarding, alighting, road link

Traffic information of the city

1. OD pairs must be determined
2. Demand of each OD pair

Accessibility of the sites should have effect in waiting time calculation

Use flow balance constraint (demand, flow relationship)

It helps to properly describe the users’ travel behavior

Wayne State University
TRCLC Conference | June 21, 2018
• SEMCOG supports coordinated, local planning with technical, data, and intergovernmental resources.
• SEMCOG’s plans improve the quality of the region’s environmental resources, make the transportation system safer and more efficient, revitalize communities, and encourage economic development.
A modeling framework for planning agencies to design network for EV charging stations based on consideration of randomness in OD demand, walking range, arrival pattern, SOC, accessibility, multi-modal transportation.

Interdisciplinary behavioral study on the drivers’ willingness to walk and adoption of multi-modal transportation based on the quality, accessibility and proximity to EV charging station.

Case study for a community with the guidance of a planning agency such as the SEMCOG. Documentation and reports on results of the study and details on the integration of the tool.
Thank You!