Service Region Design for Urban Electric Vehicle Sharing Systems

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Joint work with Long He, Ying Rong, Max Shen
Sustainability and Transportation

• Did you know that
  – Transportation: 20% of global GHG emissions?
  – VMT grew by 30% since 1995?

• Directions for Solutions?
  – Cleaner vehicles (e.g., EVs)
  – Fewer vehicles
  – Fewer vehicle-miles
Car Sharing

• Sharing of ownership
  - Pooling of resources
  → Fewer vehicles
  - Reduces 0.23 cars per household

• Increased utilization of cars
  - Incentive to improve fuel economy
  → Cleaner vehicles
  - 23 mpg (own) → 33 mpg (sharing)
Modes of Car Sharing

**ZipCar**
- Specified locations
- Stations
- Round trips

**Car2Go**
- Any street parking
- Service region
- Round trips and One-way trips

Parking

Where?

Trip types
Key Challenge: Where to Cover?

- More unbalanced demand
- Larger fleet size
- Higher setup (infrastructure) cost

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Service Region Design for EV Sharing Systems
Repositioning Flows

Afternoon

Evening

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Repositioning and Charging

- Closed networks are hard to analyze due to dependence of arrivals & departures
- Fixed population mean (FPM) approximation → Open network [Whitt, MS]

Closed Queueing Network
Fundamental Trade-off: More vs. Less Coverage

- More imbalanced demand
- Larger fleet size
- Higher setup (infrastructure) cost

- More travel needs covered
- Higher value of covering other locations
Customer Adoption

Utility of serving dest. $j$ for a cust. in $i$

$$\sum_{j \in I} a_{ij} x_{ij} \geq b$$

Aspiration level

Binary coverage decision variable

$$\sum_{j \in I} a_{ij} x_{ij} \leq b$$
Distributionally-Robust Optimization

Enlarged ambiguity set where true distribution may reside within

Consider worst case in ambiguity set

Statistical estimation

Not perfectly reliable

Data

Optimization

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Robust Optimization

- Worst case of customer adoption rate in region $i$:

$$ q_i \leq \inf_{p \in P} \text{Prob}\left( \sum_{j \in I} a_{ij} x_j \geq b \right) $$

Given mean, covariance of nonnegative $a_{ij}$

Copositive Cone Constraints

Semi-definite Constraints

Copositive Cone

$$ CO_n := \{ A \in S_n | \forall v \in \mathbb{R}_+^n, v^T A v \geq 0 \} $$

Second-order Cone Constraints
Car2Go@San Diego
Other Data Sets

- 2010 American Community Survey and ArcGIS
  - Census data at zip code level with population and income.
  - Travel distances and times between regions based on road network.

- 2010 California Household Travel Survey (CHTS)
  - Households, persons and places tables with age, income, zip codes and travel modes.

- EV charging station data from U.S. Department of Energy
  - Location, zip code, charger number and charging network (“Blink”)
Optimal Service Region

**Current operations**
Selected Zip codes: 18
Fleet size: 379 EVs

**Optimal solution**
Selected Zip codes: 35
Fleet size: 369 EVs
Observation: Supporting customers’ travel needs with zero emission, deploying EV sharing service with 369 EVs gains similar CO2 emission savings from replacing 1392 gasoline cars with EV ownership.
Observation: One-way systems show more profits with higher adoption rates than round-trip systems by serving more destinations.
Conclusion

- Car sharing: emerging business model in sharing economy
  - Potential for sustainable development with EVs
- Service region design problem
  - Adoption behavior
  - Operational characteristics
- Computationally-efficient robust formulation integrated with data
- Design questions
  - Expansion opportunities