An Agent-Based Decision Support System for Electric Vehicle Charging Infrastructure Deployment

Timothy Sweda
Diego Klabjan

Nov. 13, 2011
INFORMS Annual Meeting
Charlotte Convention Center
Charlotte, NC

NORTHWESTERN UNIVERSITY

Outline

- EVs in U.S.
- Literature Review
- Proposed Model
- Implementation
- Results
- Future Work

Electric Vehicles (EVs)

- An electric vehicle (EV) is a vehicle powered entirely or in part by electricity
- Three main types:
  - Hybrid (HEV), e.g. Toyota Prius
  - Plug-in Hybrid (PHEV), e.g. Chevrolet Volt
  - Battery (BEV), e.g. Nissan Leaf

EVs in U.S.

- Current market share is small but growing
  - HEV: 2%
  - PHEV/BEV: 0.1%
- U.S. expected to be 2nd largest global consumer of plug-in vehicles (behind China)

EVs in U.S.

- Barriers to mass EV adoption:
  - High vehicle prices
  - Gas prices still (relatively) low
  - New technology
    - Uncertainties
    - Limited choices
  - Range anxiety
  - Lack of charging infrastructure

Literature Review

- Consumer choice models:
  - Santini & Vyas (2005)
  - McManus & Senter (2009)
  - Heutel & Muehlegger (2010)
- Simulation/agent-based models:
  - Stephan et al. (2007)
  - Mahalik et al. (2009)
  - Sullivan et al. (2009)
  - Cui et al. (2011)

Literature Review

- Shortcomings of previous models:
  - Do not consider interaction between EV adoption and infrastructure growth
  - Limited study of competition among different EV types
  - For ABMs, patch-based environments prohibit micro-level analyses

Proposed Model

- Contributions:
  - Incorporate GIS shapefiles and street-level data
  - Study effect of charging infrastructure presence on EV adoption
  - Analyze adoption trends of different EV types

Proposed Model

- Agent-based model
- Agents = drivers
  - Income
  - Preferred vehicle class
  - Range anxiety
  - Greenness
  - Vehicle
    - Type
    - Fuel efficiency
    - Keep time

Proposed Model

- Environment
  - Roads
  - Houses
  - Workplaces
  - Points of interest
  - Charging stations

Proposed Model

- Each agent has weekly errands
  - Local
  - Distant
  - Work
- Spheres of social influence
  - Neighbors
  - Coworkers

Proposed Model

- PHEV/BEV drivers must recharge their vehicles periodically
- BEV drivers accumulate inconvenience and worry
  - Inconvenience: extra distance to recharge
  - Worry: distance traveled while battery is low

Proposed Model

- Driving behavior
  - All agents:
    - Must work from 9AM-5PM
    - When not at work, may run errands
    - Must obey morning/evening curfews
  - BEV agents:
    - Must seek recharging when battery gets low
    - May recharge at home, charging station, or errand with charging access
  - PHEV agents:
    - Do not actively seek recharging
    - Recharge only when already at home or at errands with charging access

Proposed Model

- Purchasing a new vehicle
  - When vehicle's age equals keep time, driver replaces vehicle with new one
  - Notation:
    - $y(a,t)$ = optimal vehicle choice for agent *a* at time t
    - $V(a)$ = set of vehicles available to agent *a*

Proposed Model

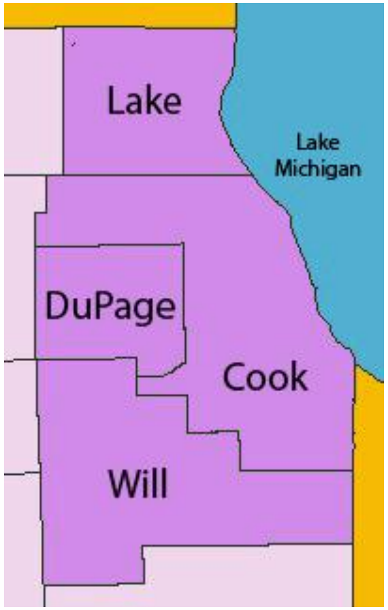
- Optimal vehicle expression:

$$y(a,t) = \underset{v \in V(a)}{\operatorname{argmin}} \left\{ \begin{matrix} A(v,t) + B(v,a,t) - C(v,a) - D(v,a,t) + \\ E(v,a) + F(v,a,t) + G(v,a) \end{matrix} \right\}$$

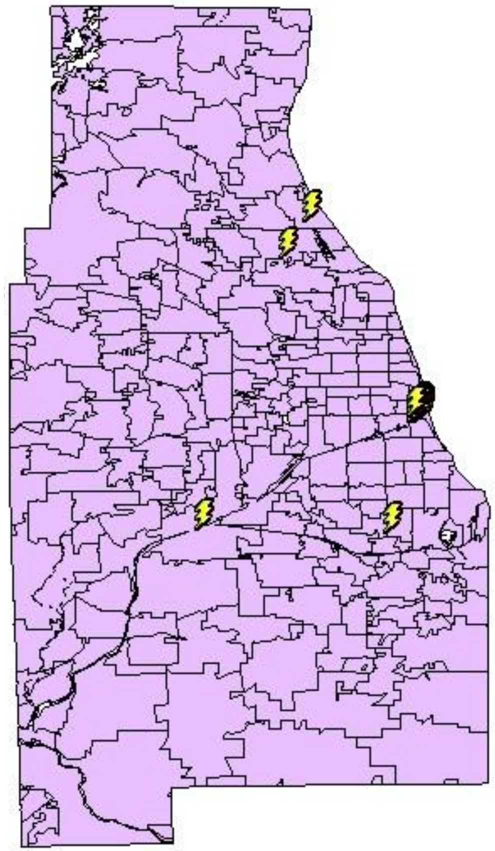
- *A*: Sticker price
- *B*: Expected fuel cost
- *C*: Green bonus
- *D*: Social influence
- *E*: Range penalty
- *F*: Infrastructure penalty
- *G*: Feature tradeoff penalty

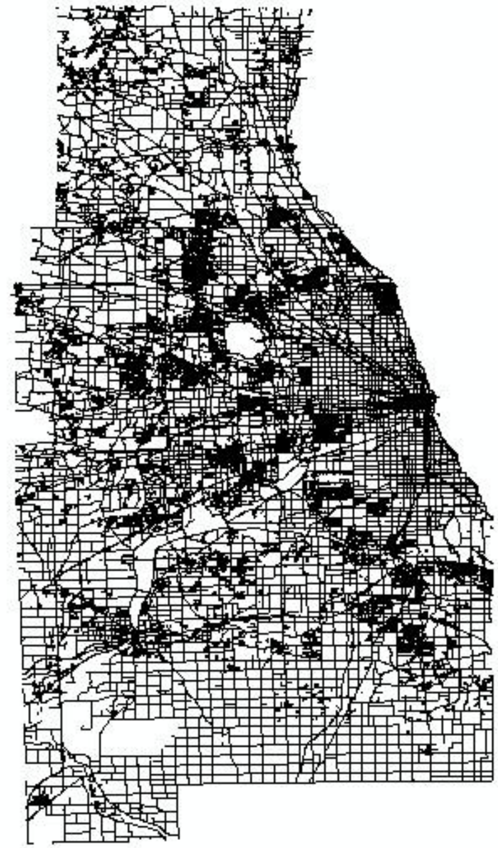
Model Implementation

- Modeling platform: Repast
- Environment: Cook, DuPage, Lake, Will counties (IL)



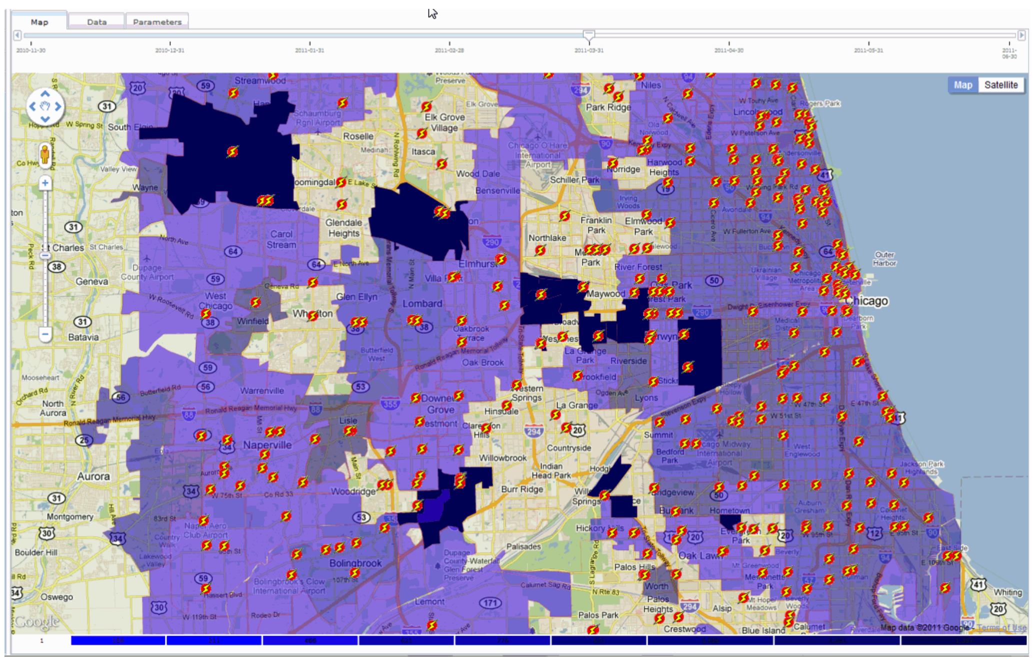
Model Implementation





Model Implementation

- Infrastructure Deployment Scenarios:
  - Base case (18 stations)
  - Prop. 1: Base+71 stations
  - Prop. 2: Base+73 stations



Results

- A priori statistics
- Post-analysis
- Trends

Results

- A priori statistics
  - Coverage

Average Distance to Nearest Charging Station

Scenario	Distance (mi.)	Std. Error (mi.)
Base	10.50	0.06
Prop. 1	5.01	0.05
Prop. 2	4.37	0.03

Results

Average Number of Nearby Charging Stations

Scenario	# Within *X* mi. (Std. Error)			
	X = 5	*X* = 10	*X* = 15	*X* = 20
Base	0.92 (.03)	3.35 (.05)	5.85 (.06)	7.91 (.07)
Prop. 1	3.69 (.08)	12.52 (.13)	23.00 (.16)	33.14 (.18)
Prop. 2	3.49 (.08)	12.21 (.13)	22.20 (.14)	32.21 (.16)

Probability of Nearby Charging Station

Scenario	Probability of Station Within *X* mi. (Std. Error)			
	X = 5	*X* = 10	*X* = 15	*X* = 20
Base	0.157 (.004)	0.517 (.005)	0.821 (.004)	0.938 (.002)
Prop. 1	0.633 (.005)	0.889 (.003)	0.949 (.002)	0.987 (.001)
Prop. 2	0.671 (.005)	0.948 (.002)	0.983 (.001)	0.995 (.001)

Results

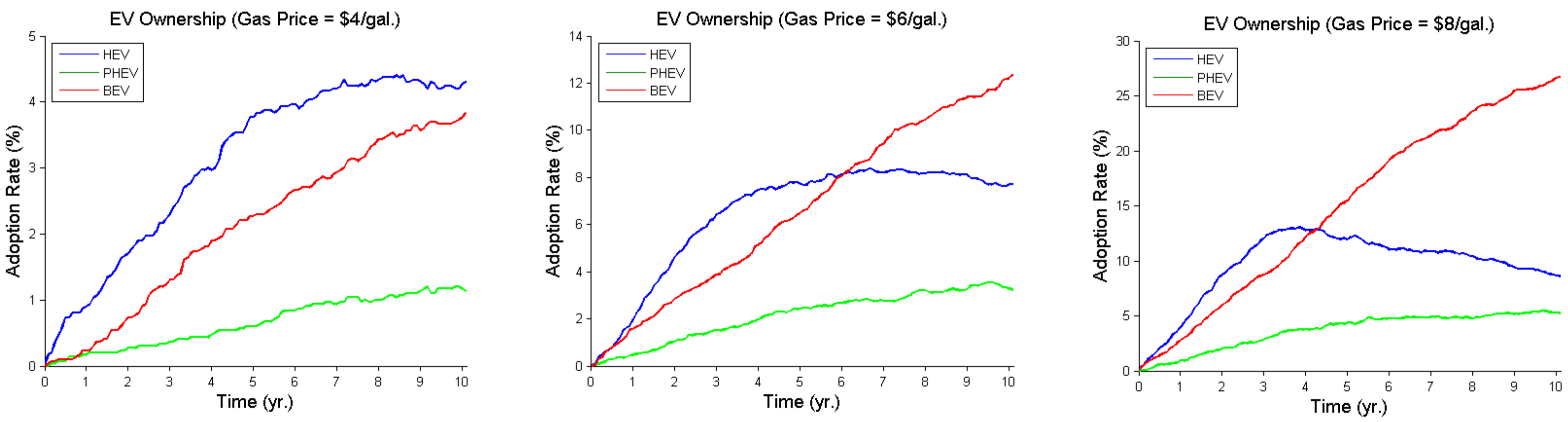
- Post-analysis
  - Inconvenience to BEV drivers

Average Annual Inconvenience Incurred by BEV Drivers

Scenario	Inconvenience (mi./yr.)	Std. Error (mi./yr.)	Electricity Cost
Base	1,239	91	$45.43
Prop. 1	757	44	$27.76
Prop. 2	667	34	$24.46

Results

- Trends
  - EV adoption vs. time vs. gas price



Work in Progress

- Quantify net emissions reduction due to widespread EV adoption
- Evaluate influence of individual charging stations on EV purchases
- Analyze clustered vs. non-clustered strategies for locating charging stations

Future Work

- Incorporate additional data to improve accuracy
- Expand simulation functionality to provide infrastructure deployment recommendations as output
- Develop optimization framework to determine best charging station locations

Thank You