Transport modeling and simulation for next generation infrastructure development: Connecting vehicle to electricity network

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Outline

• Background
  – Next generation infrastructure and car in Japan

• Battery charging behavior
  – At home
  – Within trip

• Vehicle to grid
  – Impact on electricity demand curve

• Conclusions
Next generation infrastructure

- Council for Science and Technology Policy, Japan states the need for next generation infrastructure

- Features of next generation infrastructure
  - **Smart**: information technology to forecast, control and optimize infrastructure system
  - **System**: value added as system in addition to strength of products and technology itself
  - **Global**: business strategy toward global deployment
Areas of next generation infrastructure

- Smart energy community
  - Energy management system utilizing information technology
  - Renewable energy, decentralized generating plant, etc.

- Intelligent transport system
  - Communication networking among people, vehicles and road utilizing information technology
  - Navigation system, car sharing, LRT, etc.

- Next generation infrastructure in other areas
  - Water supply, goods distribution, medical care, etc.
  - Integrated system
Passenger car ownership in Japan

Source: MLIT
## Passenger car sales ranking in Japan in 2012

<table>
<thead>
<tr>
<th>Rank</th>
<th>Model (Automaker)</th>
<th>Sales</th>
<th>Engine type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Prius (Toyota)</td>
<td>317,675</td>
<td>HV</td>
</tr>
<tr>
<td>2</td>
<td>Aqua (Toyota)</td>
<td>266,567</td>
<td>HV</td>
</tr>
<tr>
<td>3</td>
<td>Mira (Daihatsu)</td>
<td>218,295</td>
<td>Light motor</td>
</tr>
<tr>
<td>4</td>
<td>N BOX (Honda)</td>
<td>211,156</td>
<td>Light motor</td>
</tr>
<tr>
<td>5</td>
<td>Fit (Honda)</td>
<td>209,276</td>
<td>Small / HV</td>
</tr>
<tr>
<td>6</td>
<td>Wagon R (Suzuki)</td>
<td>195,701</td>
<td>Light motor</td>
</tr>
<tr>
<td>7</td>
<td>Tanto (Daihatsu)</td>
<td>170,609</td>
<td>Light motor</td>
</tr>
<tr>
<td>8</td>
<td>Move (Daihatsu)</td>
<td>146,016</td>
<td>Light motor</td>
</tr>
<tr>
<td>9</td>
<td>Alto (Suzuki)</td>
<td>112,002</td>
<td>Light motor</td>
</tr>
<tr>
<td>10</td>
<td>Freed (Honda)</td>
<td>106,316</td>
<td>Small / HV</td>
</tr>
</tbody>
</table>

**HV**: hybrid vehicle

*Source: Nikkei Newspaper*
Electric vehicles and Plug-in hybrid vehicle in Japan

i-MiEV 2009

Leaf 2010

Prius plug-in hybrid 2012

More energy efficient, but more electricity dependent
Battery charging at home

• Analysis on charge timing choice behavior of plug-in hybrid vehicles in Toyota City, Japan
  – This is a part of the results obtained by joint research with Toyota Motor Corporation
Smart Melit (Smart Mobility & Energy Life in Toyota City) project

- Toyota City, Japan
- 67 new houses, some with plug-in hybrid Prius
- HEMS (Home Energy Management System)
- DRP (demand response point) system
Smart house

Visualization by HEMS (home energy management system)

DRP (demand response point) portal

PHV charger

PHV

PHV charging monitor
Example of electricity demand curve

Scheduled to fill-up at 4:00
DRP (demand response point)

- Peak pricing by point system
- Low at daytime (solar energy) & high at evening (more activity at home)
Distribution of returning home timing

Many cars return home at 18 to 20 o’clock, which potentially cause peak demand
Charging time is shifted by demand response point system

With demand response point

W/O demand response point
Charge timing choice model

- Multinomial logit model

- 12 Prius plug-in hybrid vehicles
- 2011/10/1 to 2012/10/31
- 4615 cases

No charge

Just after came home

Cheapest timing

Other

Cheapest timing before the next vehicle use

Didn’t change the setting of on-timer previously set, or by mistake
## Charge timing choice model

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Variable</th>
<th>Coef.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>No charge</strong></td>
<td>Constant</td>
<td>1.34**</td>
</tr>
<tr>
<td></td>
<td>Drive distance (&lt;24 km)</td>
<td>-0.10**</td>
</tr>
<tr>
<td></td>
<td>Long distance dummy (&gt;24 km)</td>
<td>-0.38**</td>
</tr>
<tr>
<td><strong>Just after came home</strong></td>
<td><strong>Price</strong> for energy conscious person</td>
<td>-0.044**</td>
</tr>
<tr>
<td></td>
<td><strong>Price</strong> for energy unconscious person</td>
<td>-0.065**</td>
</tr>
<tr>
<td></td>
<td>Return home at daytime (9-16)</td>
<td>0.70**</td>
</tr>
<tr>
<td><strong>Cheapest time</strong></td>
<td>Constant</td>
<td>-0.69**</td>
</tr>
<tr>
<td></td>
<td><strong>Price</strong> for energy conscious person</td>
<td>-0.016**</td>
</tr>
<tr>
<td></td>
<td><strong>Price</strong> for energy unconscious person</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>Housewife dummy</td>
<td>0.66**</td>
</tr>
<tr>
<td></td>
<td>Return home at evening (17-23)</td>
<td>1.41**</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td>Constant</td>
<td>-0.96**</td>
</tr>
<tr>
<td></td>
<td>Return home at evening (17-23)</td>
<td>0.65**</td>
</tr>
<tr>
<td></td>
<td>Same as the last charge dummy</td>
<td>2.21**</td>
</tr>
<tr>
<td>Log-likelihood (0)</td>
<td></td>
<td>-5774</td>
</tr>
<tr>
<td>Log-likelihood at convergence</td>
<td></td>
<td>-4415</td>
</tr>
<tr>
<td>Adjusted rho-square</td>
<td></td>
<td>0.233</td>
</tr>
</tbody>
</table>

** 1%, * 5%
Sensitivity of the estimated model

Base case: High energy conscious male driver returned home in evening after 10 km drive

<table>
<thead>
<tr>
<th>Electricity price</th>
<th>No charge</th>
<th>Just after came home</th>
<th>Cheapest timing</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>No DRP (20.9 JPY)</td>
<td>35%</td>
<td>47%</td>
<td></td>
<td>18%</td>
</tr>
<tr>
<td>Evening price</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20.9 -&gt; 28 JPY</td>
<td>36%</td>
<td>8%</td>
<td>38%</td>
<td>19%</td>
</tr>
<tr>
<td>+ Midnight price</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20.9 -&gt; 10 JPY</td>
<td>34%</td>
<td>7%</td>
<td>42%</td>
<td>18%</td>
</tr>
</tbody>
</table>

Charge timing is easier to change than the timing of air conditioner usage, etc.
Battery charging within trip

• The timing of mid-trip electric vehicle charging
  – This is a part of the results obtained by the Project Consigning Technology Development for Rational Use of Energy (Promotion of aggregation and sharing of probe information)
  – The dataset was provided by Japan Automobile Research Institute (JARI)
Fast charger deployment in Japan

Source: CHAdeMO Association
Trade-off between battery size and fast charger density

How to optimize battery size & fast charger deployment?

- Drivers charge battery before empty
- Charging behavior should be understood
Data

• Investigator: Japan Automobile Research Institute
• Sample: 252 company cars & 247 private cars
• Survey period: 2 years (2011.2-2013.1)
• Survey area: 42 out of 47 prefectures in Japan

• Built-in data logger with GPS & communication unit: clock time, location, vehicle state (driving, normal charging, fast charging), odometer reading, use of air-conditioner & heater, state of charge
Distribution of SOC at normal charge

Company cars are charged at the end of the working hours regardless of SOC
Distribution of SOC at fast charge

Company cars

Private cars

Battery capacity is not fully utilized
Stochastic frontier model of SOC at fast charging within trip

• Driver avoids running out of power

\[
\text{Actual remaining electricity to start charging} \geq \text{Subjective minimum electricity}
\]

• Inefficiency is added to minimum electricity

\[
\text{Actual remaining electricity} = \text{Subjective minimum electricity} + \text{Inefficiency}
\]

• Stochastic cost frontier model is applied
Distribution of subjective minimum and actual remaining charge

personal-use vehicles on working day

- Subjective minimum remaining charge has peak at 3.6kWh
- 1.5kWh of average inefficiency is estimated
Distribution of subjective minimum and actual remaining charge

- Same peak of minimum remaining charge
- Larger (1.8kWh) average inefficiency is estimated
Vehicle to grid

- Impact of electric vehicles on electricity demand curve in Nagoya, Japan
  - This is a part of the research results funded under the Environmental Research and Technology Development Fund by Ministry of the Environment
Micro simulation model of individual’s activity-travel pattern

- Nested logit model of activity type, destination, mode and rail route choice at each time period
- Sequence of activity-travel pattern is simulated
Interaction between activity-based model & dynamic traffic assignment

Equilibrium state is calculated

- Parking location, parking duration, and SOC of each EV are simulated along time of day
Scenario analysis at Nagoya, Japan

Nagoya Metropolitan Area

Population in 2020: Over 8.0 million

Zone: 520 zones
(Nagoya City is divided into 259
Average area is 1.3 km²)

Road Network:
Link: 22,466
Node: 7,600

10% of vehicles are assumed to be replaced by EV, which means 472,000 EVs
Distribution of electricity demand

- Total demand is about 31GWh
- Higher demand at midday and at CBD
Scenarios for EV charging/discharging

- Case 0: No EVs
- Case 1: Charge at home immediately after returning home
- Case 2: Charge at home during midnight
- Case 3: Charge at workplace immediately after arriving at work
- Case 4: Charge at home during midnight and discharge at workplace during daytime (until the remaining charge at 5 kWh)
Impact on electricity demand curve

- 0.1GW of daytime demand (9:00 to 16:00) can be cut by vehicle to grid at workplace
Spatial distribution of impact

• Impact is quite different between CBD and suburban area
Conclusions

• Battery charging at home causes significant electricity demand, but the timing can be controlled by peak pricing
• Battery capacity is not fully utilized, and measures to improve efficiency are needed
• Potential to cut down peak demand by vehicle to grid at workplace