Connecting vehicles to grid

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Outline

• Background

• Battery charging behavior
  – At home
  – Within trip

• Vehicle to grid

• Conclusions
Passenger car ownership in Japan

Year

10 million vehicles

Light motor passenger car (~0.66L)
Small passenger car (~2L)
Ordinary passenger car (over 2L)

Source: MLIT
### Passenger car sales ranking in Japan in 2013

<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>Aqua (Toyota)</td>
<td>262,367</td>
<td>HV</td>
</tr>
<tr>
<td>2</td>
<td>Prius (Toyota)</td>
<td>253,711</td>
<td>HV</td>
</tr>
<tr>
<td>3</td>
<td>N BOX (Honda)</td>
<td>234,994</td>
<td>Light motor</td>
</tr>
<tr>
<td>4</td>
<td>Move (Daihatsu)</td>
<td>205,333</td>
<td>Light motor</td>
</tr>
<tr>
<td>5</td>
<td>Wagon R (Suzuki)</td>
<td>186,090</td>
<td>Light motor</td>
</tr>
<tr>
<td>6</td>
<td>Fit (Honda)</td>
<td>181,414</td>
<td>Small / HV</td>
</tr>
<tr>
<td>7</td>
<td>Mira (Daihatsu)</td>
<td>157,276</td>
<td>Light motor</td>
</tr>
<tr>
<td>8</td>
<td>Note (Nissan)</td>
<td>147,634</td>
<td>Small</td>
</tr>
<tr>
<td>9</td>
<td>Tanto (Daihatsu)</td>
<td>144,629</td>
<td>Light motor</td>
</tr>
<tr>
<td>10</td>
<td>Alto (Suzuki)</td>
<td>111,361</td>
<td>Light motor</td>
</tr>
</tbody>
</table>

**HV**: hybrid vehicle

Source: Japan Automobile Dealers Association & Japan Mini Vehicle Association
Electric vehicles and Plug-in hybrid vehicle in Japan

- i-MiEV 2009
- Leaf 2010
- Prius plug-in hybrid 2012

More EVs and PHVs on the market
Electric vehicles and plug-in hybrid vehicles in Japan

More energy efficient, but more electricity dependent

Source: Next Generation Vehicle Promotion Center
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 Mobility & Energy Life project in Toyota City

- 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

*Summer*

- **PHV charge**
- **Air cond.**

*Winter*

- **PHV charge**
- **Air cond.**

- **Heat pump water heater** Scheduled to fill-up at 4:00
Many cars return home at 18 to 20 o’clock, which potentially cause peak demand.
DRP (demand response point)

• Peak pricing by point system
• Low at daytime (solar energy) & high at evening (more activity at home)
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

- No charge
  PHV can run even without charge

- Just after came home
  Cheapest timing

- Cheapest timing before the next vehicle use

- Other
  Didn’t change the setting of on-timer previously set, or by mistake

- 12 Prius plug-in hybrid vehicles
- 2011/10/1 to 2012/10/31
- 4615 cases
## 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>Price for energy conscious person</td>
<td>-0.044**</td>
</tr>
<tr>
<td></td>
<td>Price 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>Price for energy conscious person</td>
<td>-0.016**</td>
</tr>
<tr>
<td></td>
<td>Price 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>
</tbody>
</table>

Log-likelihood (0)                       -5774
Log-likelihood at convergence            -4415
Adjusted rho-square                      0.233

** 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 20.9 -&gt; 28 JPY</td>
<td>36%</td>
<td>8%</td>
<td>38%</td>
<td>19%</td>
</tr>
<tr>
<td>+ Midnight price 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

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
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 (1.8 kWh) 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 1.3km²

- **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
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