Smart Charging Management of Shared Autonomous Electric Vehicles: Opportunities & Challenges

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Why Shared Autonomous Electric Vehicles (SAEVs)?

**Autonomous**
- Alleviates “range anxiety.”
- Automated charging/fueling is easier to achieve with electric vehicles.

**Electric**
- Accelerates EV adoption to meet urban air quality & transport emissions goals.
- Fewer components lead to reduced maintenance (compared to internal combustion engine vehicles).

**Shared**
- Eliminates driver labor cost. Enables strategic relocation (avoiding spatial mismatch of demand & supply).
- High cost of automation technology incentivizes shared use.
- Alleviates “range anxiety.”
Shared Autonomous Electric Vehicle Research

Vehicle Automation

Vehicle Electrification

Use Case

EV-Grid Interaction

Research Question: What are the implications of Smart Charging for a SAEV fleet, under different electricity pricing and generation scenarios?
SAEV Modeling Framework

1. **Discrete-time SAEV Simulator**
   - **Travel Request**
     - *Being served*
     - *Unserved*
     - **Move SAEV and Update Position**
       - **SAEV Relocation**
       - **Reactive SAEV Charging**
       - **Smart Charging Framework**
         - *SOC, number of available SAEV*
   - **Trip-SAEV Matching**
     - **Generate Charging Station**
     - **Generate SAEV**
     - **Core Loop**
       - **Initialization**
       - **Operation**
     - *Energy data from grid operator*
   - **Phase 1**
   - **Phase 2**
   - **Phase 3**
Baseline Charging Strategy

• **Base strategy**
  – **Unmanaged**: charging activity mostly on peak and add strain and volatility on grid, especially in evening peak. SAEV unoccupied travel distance for charging is minimized.
  – **Distributed**: minimum charging infrastructure required.

High grid loads
Smart Charging Strategy

• **Operational level objectives**
  – Minimize SAEV electricity costs (*Time-of-Use* and *Real-Time Pricing* Scenarios)
  – Maximize self-consumption (*Renewable Generation* Scenario)
  – Objectives achieved through coordinated SAEV fleet charging assignment

• **Operational level constraints**
  – No SAEV that are in use for mobility service is considered for charging management
Travel Demand Data (PSRC 2016)

• 3700 travel analysis zones (TAZs) in the 5-county region
• 6.9k sq mi area
• 12 million vehicle-trips for a weekday
• 10% of total trips are simulated to be served by SAEV
• Average trip length is 5.9 miles
• Link travel times by 5 times-of-day (input to SAEV simulation model)
Energy Scenarios Data

• **Time-of-use** pricing scenario (*rates from Seattle City Light in 2017*)
  – Two-tier pricing structure, off-peak between 10 pm - 6 am
  – Demand charge recurring monthly

• **Real-time pricing** scenario (*LMP from ColumbiaGrid in 2017*)
  – Price updates hourly
  – Price data based on electricity wholesale market

• **PV generation** scenario (*solar integration dataset from NREL*)
  – Generalized generation pattern based on regional solar data
### Transportation Technology Assumptions

**Average energy efficiency**: 3.3 mi/kWh

**Accounts for 20% increase in energy consumption due to vehicle automation hardware and software**

**Due to non-linearity of the charging rate, 20% range reduction is assumed in FC scenarios.**

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Charging Infrastructure</th>
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<tbody>
<tr>
<td></td>
<td>Level 2 Charging</td>
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<tr>
<td><strong>Vehicle Battery Size</strong></td>
<td></td>
</tr>
<tr>
<td>40 kWh</td>
<td>132 mile range</td>
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<tr>
<td></td>
<td>7 kW/hr charge rate</td>
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<tr>
<td>90 kWh</td>
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</tr>
<tr>
<td></td>
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<td>LR-LV2 273 mile range 20 kW/hr charge rate LR-FC 218 mile range 120 kW/hr charge rate</td>
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With increased battery capacity, LR vehicles exhibit superior ability to avoid charging on-peak.
Compared to unmanaged charging, electricity costs can reduce 10% (SR SAEVs) to 34% (LR SAEVs).
When all operational costs are accounted for, **SR vehicle scenarios are still cheaper to operate on a per-mile basis.**
Sampled 10 days of LMP data (Wednesday of every 5th week) from 2017
RTP Prediction via Machine Learning

![Graph showing price over time](image)

- Price ($/MWh)
- Time (h)
- t1 to t18
- LMP
LR vehicles are able to decrease electricity cost by 36 to 43% compared to SR vehicles with smart charging.
PV Generation Results - Charging Behavior

LR EVs can reach **higher self-consumption rates (93-99%)** while SR EVs reach 81% self-consumption.
Level 2 chargers cause increased wait times for passengers. All PV Generation scenarios increase zero-occupant vehicle miles traveled.
Key Takeaways

- **Disruptive mobility** trends will change the way urban transportation systems interact with the electric grid.
- Based on simulated SAEV travel & charging behavior, the **SAEV unmanaged charging peak occurs between 6 pm and 8 pm**, which correspond to the end of PM transportation peak.
- Under **TOU pricing** structure, **SC strategies with LR vehicles can reduce energy costs** for the SAEV fleet operator while **maintaining the level of mobility service**.
- Fleet operator electricity costs can be reduced further under **RTP pricing** (especially with LR vehicles). Results suggest operator should focus on **peak-shaving** rather than valley-filling, when price is dynamic.
- **SAEV charging** can be managed to **effectively absorb PV generation**, but at the cost of **increasing zero-occupant miles traveled** (to charge).
- **Battery capacity** plays an essential role in the SAEV-grid interaction. Larger batteries enable SAEVs to act simultaneously as mobile energy user & storage. But with current battery costs & static electricity pricing, fleet operators are likely not incentivized to adopt LR vehicles.