Management of **Shared, Autonomous, Electric Vehicles: Charging & Pricing Strategies**

**T. Donna Chen**, PE, PhD  
Department of Civil & Environmental Engineering  
*University of Virginia*

**Kara M. Kockelman**, PhD, PE  
Department of Civil, Architectural & Environmental Engineering  
**Josiah P. Hanna**  
Department of Computer Science  
*University of Texas at Austin*
Urban Transportation Trends & Technologies: A New Mode for Future Transportation

Shared Autonomous Electric Vehicle (SAEV)
Self Driving Vehicles in a Shared Electric Fleet

• No more manual vehicle relocation
  • Vehicles can strategically relocate themselves.
• No more range anxiety
  • Vehicles only accept trip requests that can be completed on its remaining charge.
  • No mid-trip refueling (as is required with current carsharing services).
• On demand transportation without concern about trustworthiness of driver & cost of driver labor.
• Automated charging is easy with wireless inductive charging.
### SAEV Simulation: Trip Generation & Travel Speeds

<table>
<thead>
<tr>
<th>Equi. Pop. Density (persons/mi²)</th>
<th>Avg Trip Gen. Rate (trips/cell/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Downtown</strong> &gt;7500</td>
<td>129</td>
</tr>
<tr>
<td><strong>Urban</strong> 2000-7499</td>
<td>39</td>
</tr>
<tr>
<td><strong>Suburban</strong> 500-1999</td>
<td>11</td>
</tr>
<tr>
<td><strong>Exurban</strong> &lt;500</td>
<td>1</td>
</tr>
</tbody>
</table>

Travel Speed:

- **Peak** (7-8am, 4-6:30pm)
  - **Downtown**: 15 mi/hr (24 km/hr)
  - **Urban**: 24 (37)
  - **Suburban**: 30 (48)
  - **Exurban**: 33 (53)
- **Off-Peak** (All Other Hours)
  - **Downtown**: 15 mi/hr (24 km/hr)
  - **Urban**: 24 (37)
  - **Suburban**: 33 (53)
  - **Exurban**: 36 (58)

Represents ~2.9 million people region
Generates ~680,000 trips per day (10% of total trips)

Based on CAMPO's 2010 model
SAEV Simulation: Agent Based Model Framework

- **Trip departure times & trip distances** based on 2009 US NHTS.

![Trip Distance (mi) Distribution](image)

- **Discrete time**, modeled at 5 min. intervals.
- 2-phase **warm run** (20 days) generates charging stations & vehicle fleet.
- **Full run** simulates 50 days.
SAEV Simulation: Phase 1 Warm Run – Charging Station Generation

**Generate Traveler & Trip**
- SAEV > 5 min travel time
- SAEV ≤ 5 min travel time

**Generate SAEV with full range**

**Range Check**
- Range ≥ Distance to Traveler + Trip
- Range < Distance to Traveler + Trip

**Relocating SAEV**
- Range ≥ 2 miles*
- Range < 2 miles*

**Charging SAEV**
- Range ≥ Distance to nearest charging station
- Range < Distance to nearest charging station

**Relocate Vehicle by Block Allocation Scheme**

**Travel to Destination**

**Release Traveler**

**Travel to Passenger**

**Picks Up Traveler**

**Travel to Charging Station**

**Charging Station**

**Waitlist**
= 10 min

**Joins Waitlist**

**Call SAEV**

**Available SAEV**

**Traveler Calls**

**No Call**
SAEV Simulation: Full Run (50 Days)

Generate Traveler & Trip

- Travel to Charging Station
  - Charge at Station

In Use SAEV

- Travel to Passenger
  - Picks Up Traveler
  - Travel to Destination
  - Release Traveler

Available SAEV

- Range Check
  - Traveler Calls
    - No Call
      - Relocating SAEV
        - Range ≥ Distance to Traveler + Trip
          - Range < Distance to Traveler + Trip
            - Range < 2 miles*
              - Relocate Vehicle by Block Allocation Scheme
            - Range ≥ 2 miles*
              - Generate Traveler & Trip

Range Check

- SAEV > 5 min travel time
  - Joins Waitlist
    - Call SAEV
      - Range ≥ Distance to Traveler + Trip
        - Range < Distance to Traveler + Trip
          - Range ≥ Distance to nearest charging station

Charging SAEV

- Range < 2 miles*
  - Charge at Station

SAEV Simulation: Full Run (50 Days)

- Joins Waitlist
  - = 30 mins
  - Unserved Trip

Relocating SAEV

- Relocate Vehicle by Block Allocation Scheme

SAEV Simulation: Full Run (50 Days)

- Generate Traveler & Trip
  - Range Check
    - Traveler Calls
      - Range < Distance to Traveler + Trip
        - Range < 2 miles*
          - Relocate Vehicle by Block Allocation Scheme
        - Range ≥ 2 miles*
          - Generate Traveler & Trip

SAEV Simulation: Full Run (50 Days)

- Range Check
  - Traveler Calls
    - Range < Distance to Traveler + Trip
      - Range < 2 miles*
        - Relocate Vehicle by Block Allocation Scheme
      - Range ≥ 2 miles*
        - Generate Traveler & Trip

SAEV Simulation: Full Run (50 Days)

- Generate Traveler & Trip
  - Range Check
    - Traveler Calls
      - Range < Distance to Traveler + Trip
        - Range < 2 miles*
          - Relocate Vehicle by Block Allocation Scheme
        - Range ≥ 2 miles*
          - Generate Traveler & Trip

TOWARDS INTELLIGENT MOBILITY
Better use of space
## SAEV Simulation: Vehicle & Charging Infrastructure Combination Scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>SAV</th>
<th>SAEV</th>
<th>SAEV Fast Charge</th>
<th>LR SAEV</th>
<th>LR SAEV Fast Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range (mi)</td>
<td>400</td>
<td>80</td>
<td>64</td>
<td>200</td>
<td>160</td>
</tr>
<tr>
<td>Refuel/Recharge Time (min)</td>
<td>15</td>
<td>240</td>
<td>30</td>
<td>240</td>
<td>30</td>
</tr>
<tr>
<td># of Charging/Fueling Station Sites</td>
<td>1062</td>
<td>1562</td>
<td>1573</td>
<td>1555</td>
<td>1517</td>
</tr>
<tr>
<td>Fleet Size</td>
<td>29,939</td>
<td>57,279</td>
<td>39,593</td>
<td>41,179</td>
<td>31,859</td>
</tr>
<tr>
<td>Avg Daily Miles per Veh</td>
<td>259</td>
<td>131</td>
<td>197</td>
<td>190</td>
<td>241</td>
</tr>
<tr>
<td>Avg Daily Trips per Veh</td>
<td>22.3</td>
<td>11.4</td>
<td>16.9</td>
<td>16.3</td>
<td>20.8</td>
</tr>
<tr>
<td>Veh Replacement Rate</td>
<td>7.32</td>
<td>3.73</td>
<td>5.53</td>
<td>5.33</td>
<td>6.82</td>
</tr>
</tbody>
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SAEV Simulation: Peak 5 Min Vehicle Activity

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</thead>
<tbody>
<tr>
<td>Unused/Relocating Vehicles</td>
<td>4339</td>
<td>8741</td>
<td>10359</td>
<td>5145</td>
<td>6408</td>
</tr>
<tr>
<td>Charging Vehicles</td>
<td>2085</td>
<td>27668</td>
<td>6459</td>
<td>14340</td>
<td>2288</td>
</tr>
<tr>
<td>In Use Vehicles</td>
<td>23515</td>
<td>20869</td>
<td>22774</td>
<td>21693</td>
<td>23162</td>
</tr>
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## SAEV Simulation: Vehicle & Charging Infrastructure Combination Scenarios

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<td>200</td>
<td>160</td>
</tr>
<tr>
<td>Refuel/Recharge Time (min)</td>
<td>15</td>
<td>240</td>
<td>30</td>
<td>240</td>
<td>30</td>
</tr>
<tr>
<td>% Trips Unserved</td>
<td>2.13%</td>
<td>3.94%</td>
<td>4.36%</td>
<td>2.29%</td>
<td>2.73%</td>
</tr>
<tr>
<td>Avg Trip Distance (mi)</td>
<td>10.06</td>
<td>9.41</td>
<td>9.08</td>
<td>10.02</td>
<td>10.02</td>
</tr>
<tr>
<td>Avg Wait Time Per Trip (min)</td>
<td>9.29</td>
<td>8.10</td>
<td>7.67</td>
<td>8.44</td>
<td>9.53</td>
</tr>
<tr>
<td>Avg Range Remain. at Recharge (mi)</td>
<td>1.62</td>
<td>43.09</td>
<td>40.72</td>
<td>5.42</td>
<td>2.47</td>
</tr>
<tr>
<td>% “Empty Vehicle” Travel</td>
<td>6.64%</td>
<td>10.69%</td>
<td>14.02%</td>
<td>7.09%</td>
<td>7.05%</td>
</tr>
<tr>
<td>Max % of Concurrent Charging Vehicles</td>
<td>7.45%</td>
<td>52.57%</td>
<td>41.68%</td>
<td>40.20%</td>
<td>7.46%</td>
</tr>
</tbody>
</table>
SAEV Simulation: “Empty” Miles Traveled

- **SAEV**
  - Occupied Miles Traveled: 89.3%
  - Unoccupied Miles for Relocation: 10.7%
  - Unoccupied Miles for Charging/Refueling: 2.5%
  - Unoccupied Miles for Trips: 4.0%

- **SAEV Fast Charge**
  - Occupied Miles Traveled: 86.0%
  - Unoccupied Miles for Relocation: 14.0%
  - Unoccupied Miles for Charging/Refueling: 5.0%
  - Unoccupied Miles for Trips: 6.1%

- **LR SAEV**
  - Occupied Miles Traveled: 92.9%
  - Unoccupied Miles for Relocation: 7.1%
  - Unoccupied Miles for Charging/Refueling: 4.6%
  - Unoccupied Miles for Trips: 1.9%

- **LR SAEV Fast Charge**
  - Occupied Miles Traveled: 92.9%
  - Unoccupied Miles for Relocation: 7.1%
  - Unoccupied Miles for Charging/Refueling: 4.9%
  - Unoccupied Miles for Trips: 0.7%
## Financial Analysis: Cost Assumptions

<table>
<thead>
<tr>
<th></th>
<th>Low Cost</th>
<th>Medium Cost</th>
<th>High Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vehicle Capital</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAEV (per vehicle)</td>
<td>$35,000</td>
<td>$40,000</td>
<td>$55,000</td>
</tr>
<tr>
<td>LR SAEV (per vehicle)</td>
<td>$45,000</td>
<td>$50,000</td>
<td>$80,000</td>
</tr>
<tr>
<td>Replacement battery (per kWh)</td>
<td>$240</td>
<td>$405</td>
<td>$570</td>
</tr>
<tr>
<td><strong>Vehicle Operations</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance (per mile)</td>
<td>$0.06</td>
<td>$0.06</td>
<td>$0.07</td>
</tr>
<tr>
<td>Insurance &amp; Registration (per vehicle-year)</td>
<td>$1,280</td>
<td>$1,600</td>
<td>$1,920</td>
</tr>
<tr>
<td>Electricity (per kWh)</td>
<td>$0.11</td>
<td>$0.13</td>
<td>$0.26</td>
</tr>
<tr>
<td><strong>Charging Infrastructure</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level II Charging (per charger)</td>
<td>$8,000</td>
<td>$12,000</td>
<td>$18,000</td>
</tr>
<tr>
<td>Level II Annual Maintenance (per charger)</td>
<td>$25</td>
<td>$40</td>
<td>$50</td>
</tr>
<tr>
<td>Level III Charging (per charger)</td>
<td>$10,000</td>
<td>$45,000</td>
<td>$100,000</td>
</tr>
<tr>
<td>Level III Annual Maintenance (per charger)</td>
<td>$1,000</td>
<td>$1,500</td>
<td>$2,000</td>
</tr>
</tbody>
</table>
Financial Analysis: Equivalent Cost Per Occupied Mile Traveled (Mid-Cost Scenario)

*Employing charging strategy with 75% max range reduces costs by $0.020 per mile.

**Adding cost of wireless charging (currently available for Level II chargers) adds $0.002 to $0.003 per mile.

***Using attendants at charging stations adds $0.077 to $0.085 per mile.
Conclusions

Each SAEV can replace 3.7 to 6.8 privately owned vehicles while producing an additional 7 to 14% of “empty” travel.

Many tradeoffs in selection of SAEV vehicles and charging infrastructure:

• Least expensive to operate is SAEVs with Level II chargers.
• Increased capital investment (LR EVs & Level III chargers) translates to decreased fleet size, unserved trips, wait times, “empty” VMT, and peak hour electricity demand.

The competitiveness of SAEVs against SAVs hinges on wireless automated charging.

• With wireless recharging, a fleet of SAEVs can be operated at $0.41 to $0.47 per occupied mile ($0.25 to $0.29 per occupied km) traveled, competitive with SAVs when gasoline is $3.50/gallon ($0.91/liter)
• Without wireless recharging, a fleet of SAEVs are only price competitive with SAVs when gasoline is $4.35 to $5.70 per gallon ($1.13 to $1.48 per liter)
Some Limitations

• **Charging station generation** process maximizes coverage but does not consider budget.

• Poisson-based trip generation process does not represent sufficient variation in cell trip generation rates in outlying areas.

• Trip generation rates are not tied to **zonal socio-demographics** (no variation in trip characteristics from cell to cell).
Thank you for your time! Questions?

T. Donna Chen
tdchen@virginia.edu
cee.virginia.edu/tdonnachen

Kara Kockelman
kkockelm@utexas.edu
www.caee.utexas.edu/prof/kockelman

Josiah Hanna
jphanna@cs.utexas.edu
www.cs.utexas.edu/~jphanna