REGIONAL OPERATIONS OF SHARED AUTONOMOUS VEHICLES (SAVs) – WITH & WITHOUT DYNAMIC RIDESHIRING (DRS)

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Market for + Simulation of Shared AV Operations

- **Less than 20%** of newer (& 15% of all) personal vehicles are in-use at peak times, even with 5-minute pickup & drop-off buffers.

- **Car-sharing** programs like Car2go & ZipCar have expanded quickly, with number of U.S. users doubling every year or two, over the past decade.

- **Shared Autonomous Vehicles (SAVs)** can help overcome car-sharing barriers, like return-trip certainty & vehicle access distances.

- As tech prices fall, **SAVs should compete very well with transit systems in most US markets.**
Our First Agent-Based Model Design

- Grid-based 10 mi x 10 mi urban area with 0.25-sq. mile zones.

- **Trip generation:**
  - Poisson-based PK & OP counts for trip generation, every 5 minutes.
  - Higher trip production & attraction rates closer to city center.
  - Mostly round-trip travel, with 78% travelers returning via SAVs.
  - Random departure times & trip distances (2009 NHTS).

- SAVs travel at fixed speeds, with 5 min. intervals.

Graphs showing:
- Trip Generation
- Dwell Times (hrs.)
- Trip Distances (mi.)
Example: One SAV's 24-hour Journey

- **Urban Core**
  Higher AM Trip Attraction

- **Outer Periphery**
  Higher PM Trip Attraction

- **Blue Arrows**
  Serving Riders

- **Red Arrows**
  SAV Relocation
Town & City Results

- **100 days simulated**, with each SAV consistently replacing 9 to 13 household vehicles.
- Avg. wait time ≈ 2.8 min, but 11% new/induced (empty-vehicle) VKT.
- **5% to 50%** (GHG vs. VOCs) life-cycle emissions savings thanks to smaller vehicles, fewer cold starts, & less parking infrastructure!

*Extending this to 12 mi x 24 mi central Austin, with actual network & trip patterns delivers similar results...*

- **1:10 & 1:8 vehicle replacement** rates (with & w/o DRS)
- **System pays for itself** with just $1/mile fares!
- **DRS saves more emissions**. And VMT even falls (vs. BAU) at high adoption levels (>300,000 person-trips/day), since more travelers’ trips overlap in time & space.
What if... SAVs Serve the Entire Region? & Are SA ElectricVs?
Chaging Station Generation via 30-day Initial Run

1. **Check for unmet requests**
   - If there are no new requests, try again in the next timestep.
   - If there are unmet requests, proceed.

2. **Find closest SAEV**
   - Determine if SAEV has range to meet trip request.
     - If yes, send SAEV to serve trip.
     - If no, continue to the next step.

3. **Is a charging station also in range?**
   - If yes, SAEV heads to closest station.
   - If no, create new station at vehicle's location.

4. **SAEV begins charging**
   - SAEV is removed from consideration.

Next timestep: \( t = t + 1 \text{sec} \)
Example Station Locations

- **Charging stations** generated based on demand.
- #Stations formed depends only on **vehicle range**...

**LEFT SIDE** = 200-mile range

**RIGHT SIDE** = 60-mile range
# Austin SAEV Results

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Hybrid SAEV</th>
<th>Slow Charge, Short-Range SAEV</th>
<th>Slow Charge, Long-Range</th>
<th>Fast Charge, Long-Range</th>
<th>Fast Charge, Short-Range</th>
<th>Fast Charge, Long-Range, Smaller Fleet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range (mi)</td>
<td>525</td>
<td>60 mi</td>
<td>200</td>
<td>200</td>
<td>60</td>
<td>200</td>
</tr>
<tr>
<td>Recharge/Refuel Time (min)</td>
<td>2</td>
<td>240 min</td>
<td>240</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td># of Charging/Gas Stations</td>
<td>19</td>
<td>155 stas.</td>
<td>155</td>
<td>155</td>
<td>155</td>
<td>155</td>
</tr>
<tr>
<td>Fleet Size (# vehicles)</td>
<td>5,893</td>
<td>5,893 vehs</td>
<td>5,893</td>
<td>5,893</td>
<td>5,893</td>
<td>4,124</td>
</tr>
<tr>
<td>Avg. Daily miles per Vehicle</td>
<td>452</td>
<td>201 mi/veh</td>
<td>354</td>
<td>441</td>
<td>355</td>
<td>501</td>
</tr>
<tr>
<td>% of Unserved Trips</td>
<td>1.62%</td>
<td>60.6%</td>
<td>19.4%</td>
<td>2.67%</td>
<td>16.2%</td>
<td>15.2%</td>
</tr>
<tr>
<td>Avg. Daily Trips per Vehicle</td>
<td>28.5</td>
<td>11.4 trips/d</td>
<td>23.4</td>
<td>28.2</td>
<td>24.3</td>
<td>35.1</td>
</tr>
<tr>
<td>Avg Wait Time Per Trip (min)</td>
<td>4.45</td>
<td>9.82 min</td>
<td>8.76</td>
<td>5.49</td>
<td>6.16</td>
<td>9.55</td>
</tr>
<tr>
<td>% Unoccupied Travel</td>
<td>6.05</td>
<td>13.1%</td>
<td>7.88</td>
<td>6.86</td>
<td>14.2</td>
<td>8.62</td>
</tr>
<tr>
<td>% Travel for Charging</td>
<td>0.65</td>
<td>5.59%</td>
<td>1.26</td>
<td>1.05</td>
<td>5.34</td>
<td>1.27</td>
</tr>
</tbody>
</table>

- **Fleet size is key** to lower **response times**. Tripling fleet (from 9:1 to 3:1 travelers per SAEV) lowers average response times by >75%.
- **Longer charge times** **increase** response times & **unserved trips** rise dramatically.
- **Longer ranges** lower empty VMT & shares of unserved trips.
- **Trips in Austin’s urban core served best** (e.g., never exceed 30-min wait times).
SAEV Cost Assumptions

• **Conventional BEV Costs:** $25,000 (short range) to $35,000 (long-range)
• **Self-driving Technology Cost:** $5,000 to $25,000 per vehicle
• **Battery Replacement:** $100 - $190 per kWh (once per vehicle life)
• **Vehicle Maintenance:** 5.4¢ to 6.6¢ per mile
• **Insurance & Registration:** $550 - $2,200 per vehicle-year
• **Electricity:** 8¢ to 20¢ per kWh
• **Level II Chargers:** $8,000 - $18,000 each
• **Level II Charger Maintenance:** $25 - $50 per year, per charger
• **Fast (Level III) Charger:** $10,000 - $100,000 per charger
• **Fast Charger Maintenance:** $1,000 - $2,000 per year, per charger
• **Station Properties:** $1,980 to $6,900 per vehicle space (based on location)
# Financial Results: Costs per Mile

<table>
<thead>
<tr>
<th>Mid-Range Expected Costs per mile</th>
<th>Hybrid SAV</th>
<th>Slow Charge, Short-Range</th>
<th>Slow Charge, Long-Range</th>
<th>Fast-Charge, Long-Range</th>
<th>Fast-Charge, Short Range</th>
<th>Fast-Charge, Long-Range, Reduced Fleet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity/Fuel</td>
<td>6.39¢/mi</td>
<td>4.51</td>
<td>4.26</td>
<td>4.21</td>
<td>4.57</td>
<td>4.29</td>
</tr>
<tr>
<td>Vehicle Maint., Admin + Attendants</td>
<td>18.4¢/mi</td>
<td>19.7</td>
<td>18.6</td>
<td>18.4</td>
<td>19.9</td>
<td>18.7</td>
</tr>
<tr>
<td>Charger Costs (Land + Infrastructure)</td>
<td>n/a</td>
<td>3.57</td>
<td>1.35</td>
<td>2.15</td>
<td>6.30</td>
<td>2.20</td>
</tr>
<tr>
<td>Vehicle Purchase</td>
<td>19.6¢/mi</td>
<td>27.7</td>
<td>29.4</td>
<td>28.3</td>
<td>25.3</td>
<td>28.4</td>
</tr>
<tr>
<td>Battery Costs</td>
<td>n/a</td>
<td>1.58</td>
<td>4.91</td>
<td>4.85</td>
<td>1.60</td>
<td>4.95</td>
</tr>
<tr>
<td>Total Costs per Mile</td>
<td>45¢/mi</td>
<td>59¢/mi</td>
<td>59¢/mi</td>
<td>59¢/mi</td>
<td>58¢/mi</td>
<td>59¢/mi</td>
</tr>
<tr>
<td>Daily Vehicle Profit ($1/mile fare)</td>
<td>$234/veh-day</td>
<td>$72</td>
<td>$132</td>
<td>$170</td>
<td>$126</td>
<td>$187</td>
</tr>
<tr>
<td>#Trips/vehicle-day</td>
<td>28 trips/veh-day</td>
<td>11</td>
<td>23</td>
<td>28</td>
<td>24</td>
<td>35</td>
</tr>
<tr>
<td>Response time/trip</td>
<td>4.4 min</td>
<td>9.8</td>
<td>8.8</td>
<td>5.5</td>
<td>6.2</td>
<td>9.6</td>
</tr>
</tbody>
</table>
Easier travel → Added congestion?

+10% from **empty driving** in **Shared AVs** (SAVs).
+10% VKT **longer urban trips** to more distant stores & such.
+5 to 15% from **mode shifts** away from transit & walk modes.
+10% from “driving” by **under-served populations** (elderly, infirm, & youth).
+10% from **shift away from airline** travel on trips < 800 km.
Perhaps +10% from **land use changes**? (sprawl)

→ **VKT/capita is likely to rise > 25%**

**Central Question:** Can **tolling strategies** keep traffic moving while improving social welfare?
Regional Results: Mode Splits + VMT

LOW DRS FARE: 10¢ pickup + 5¢/mi + 2¢/min

SAV AVAILABILITY
(1 SAV FOR EVERY X TRAVELERS)

* with tolls of 5¢/min delay
%Empty VMT, %Idling, & Avg Veh Occupancy

LOW DRS FARES: 10¢ pickup + 5¢/mi + 2¢/min

- Empty VMT
- Idle Hours in 24h
- AVO

SAV Availability
(1 SAV for Every X Travelers)

* with tolls of 5¢/min delay
Profits + Toll Revenues + Trips/day/SAV

LOW DRS FAREs: 10¢ pickup + 5¢/mi + 2¢/min

- Revenue
- Tolls Paid
- Avg. Trips Served

SAV Availability
(1 SAV for Every X Travelers)

* with tolls of 5¢/min delay
In Conclusion…

- CAVs offer tremendous benefits for mobility, safety & parking, but will add VMT & congestion (& require energy).
- SAVs offer a new & exciting (transit?) mode, with each SAV replacing ~8 personal vehicles, for equivalent # car trips.
- SAVs add 7-15% extra VMT (though DRS may reduce VMT), but can bring cost & emissions savings + transit operator profits.
- Smart system management practices - like credit-based congestion pricing - are also needed, in most settings, to avoid gridlock, sprawl, greater energy use, & other downsides.
- Singapore helps lead the way! (but needs charging stations 😊)
Thank you for a fantastic conference!

Questions & Suggestions?

>30 CAV papers & reports at www.caee.utexas.edu prof/kockelman
AVs with CBCP References (2019)

