Convergence of Technologies

- Research focus is on operational impacts of simultaneous implementation of 3 technologies (shared, automated, electric) in various use cases.

**Shared Autonomous Electric Vehicle (SAEV)**
Why SAEVs?

- **Autonomous**
  - Eliminates driver labor cost. Enables strategic relocation (avoiding spatial mismatch of demand & supply).

- **Electric**
  - Fewer components lead to reduced maintenance (compared to internal combustion engine vehicles).

- **Shared**
  - High cost of automation technology incentivizes shared use.

- **Alleviates “range anxiety.”**
  - Accelerates EV adoption to meet urban air quality & transport emissions goals.

- Automated charging/fueling is easier to achieve w/ electric vehicles
Shared Autonomous Electric Vehicle
Chen Research Group

Vehicle Automation

Shared AV

EV Range & Charging Infrastructure

Vehicle Electrification

Door-to-Door service (single occupant)
Door-to-Door service (with ridesharing)
First/Last Mile Connection with Transit

Use Case

Smart Charging Management

EV-Grid Interaction

SAEV Modeling Framework

- **Trip Generation**
  - Use local travel demand model data to generate trips to simulate origin-destination travel demand

- **Charging Station Generation**
  - Charging station site selection to ensure sufficient infrastructure coverage

- **SAEV Fleet Generation**
  - Determine the necessary fleet size to serve travel demand

- **Operation**
  - Continuous daily operation based on the station and fleet configuration
SAEV Simulator Implementation

- Available vehicles
- Vehicles at capacity
- Relocating vehicles
- Trip origins
- Trip destinations

Real Time: 2:31:46
Simulation Time (2X): 5:3:39
Trips Scheduled to load at: 5:53:36
Number of Trips Loaded: 2068.00
Avg. Vehicle Speed (mi/hr): 14.02
Vehicle Miles Traveled (VMT): 3690.59
Instantaneous Occupancy: 2.14
Average Occupancy: 2.06
Trips Served: 99.52%
Average Wait Time (min): 3.59
Average Travel Time (min): 3.72
Total Miles to Charger: 0.00
Total Relocation Miles: 767.46
Vehicles in Use: 8
Vehicles Idle: 76
Vehicles Charging: 0
Vehicles Relocating: 1
Total Charges: 0
Avg. Vehicle Idle Time (min): 234.60
Vehicle Range: 1.68.04
EV Technology Assumptions

• **SR** EV: 40 kWh battery (Similar to Nissan Leaf)
• **LR** EV: 90 kWh battery (Similar to Tesla Model 3)

• **LV2**: Level 2 charger, 7 or 20 kW power
• **FC**: DC fast charger, 70 or 120 kW power

• **Average energy efficiency**: 0.33 kWh/mi
  • Accounts for 20% increase in energy consumption due to vehicle automation hardware and software
SAEV Model Assumptions

We attempt to model “Year 1” operations of a SAEV fleet, where:

• Fleet serves 10% of a region’s travel demand
• Land use and travel behavior have not yet been influenced by SAEVs
• Charging station capacity is not explicitly modeled, only charging station locations
SAEV Use Case: Door-to-Door Service

Case studies in Austin, Texas
Door-to-Door SAEV Service (Single Occupant): Fleet Size by Vehicle & Charging Infrastructure

• **Fast charging** infrastructure & longer **EV range** reduces required fleet size.

• Each SAEV can **serve 11 to 21 trips per day**, equivalent to replacing **3.7 to 6.8 privately owned vehicles**. (SAVs serve, on average, 22 trips/day)
“Empty” VMT constitutes 7 to 14% of all miles traveled. (For SAVs, “empty” VMT is 6.6%)

- Short range SAEVs incur more zero occupant miles due to more trips for recharging.
Door-to-Door SAEV Service (Single Occupant): Operational Cost Per Occupied-Mile Traveled

- **SR SAEVs with Level II charging** are cheapest to operate on a per-mile basis, even if this configuration incurs highest % “empty” VMT (increases congestion) and require biggest fleet (requires more land for charging spots).
SAEV Door-to-Door Service with **Dynamic Ridesharing**

**SR SAEV**

- "Empty" VMT comprises 13-16% of total VMT for SR SAEV scenario and 9-11% for LR SAEV scenario.
- Assuming all travelers are willing to participate in ridesharing, about 35% of all VMT include at least two passengers.
- One SAEV with dynamic ridesharing can replace 8 to 13 privately owned vehicles.

**LR SAEV**
SAEV Door-to-Door Service with Dynamic Ridesharing

- As the number of pickup & drop-off locations increase in an itinerary of each vehicle, travelers experience longer **wait times**.
- Benefits associated with larger vehicles begin to diminish as reflected by marginal decrease in **fleet size** as vehicle capacity increases.
- Higher occupancy rates & lower VMT results in the reduced **number of charging stations**.

![Graphs showing the relationship between vehicle capacity and various metrics such as average wait time per trip, SAEV fleet size, and number of charging stations.]
SAEV Door-to-Door Service w/ Dynamic Ridesharing

• Though the total % of trips served exceeds 96% in all scenarios, the likelihood of matching a vehicle with a passenger varies by time of day. During peak hours, matching rates can be as low as 85%.
SAEV Use Case: **First/Last Mile Connection**

Case study in Seattle, Washington
SAEVs for First/Last Mile Connection

- SAEVs can help **decrease the demand for scarce parking spots** at Park & Rides, and reduce the parking infrastructure requirements on valuable real estate.

Case study at Tukwila Light Rail Station in Seattle, Washington
- 2016 survey of rider origin-destinations
- Hourly boarding & alighting data
Enabling ridesharing in SAEVs for first/last mile mobility reduce system-wide VMT by 37% (compared to single occupancy).

If all travelers participate in ridesharing, 40-45% of all VMT include at least two passengers, and ridematch rate is higher during AM & PM peaks.

“Empty” VMT remains around 20% with ridesharing in all vehicle & charging infrastructure scenarios.

One SAEV with dynamic ridesharing can replace 20 to 34 “park & ride” vehicles.

The fleet size reduction benefit going from SR to LR vehicles is diminished, because trips are shorter in distance.
SAEV-Grid Interaction

Case study in Seattle, Washington
Charging “as needed” minimizes SAEV “empty” travel distance for charging, but exhibits **peak charging periods** which coincide with existing peak hours of electricity use.
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
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).
Under **real time electricity pricing** scheme, **LR vehicles** are able to decrease electricity cost by 36 to 43% compared to SR vehicles with smart charging. Adding **fast charging infrastructure** also allows more **opportunistic charging** during low priced periods.
SAEVs: Key Takeaways

• When ridesharing is considered, SAEVs are more efficient at serving first/last mile connection trips than door-to-door trips (higher average occupancy, better ridematch rates during peak hours).
  • How will we encourage disruptive mobility as part of a multimodal trip rather than a new replacement mode?
• “Empty” VMT as a singular measure is not indicative of service efficiency. Service configurations & use cases with higher “empty” VMT can mean higher average vehicle occupancy across all VMT.
  • Don’t let the bad publicity of the empty autonomous car get in the way of the real focus: higher average occupancy.
• Charging station capacity can be reduced with longer range vehicles, fast charging infrastructure, and higher ridematch rates.
  • But shorter range vehicles & Level II charging infrastructure are cheaper for the fleet operator to acquire & implement.
• Battery capacity plays an essential role in SAEV-grid interactions. Larger batteries enable SAEVs to act simultaneously as mobile energy user & storage. But with current battery costs & static electricity pricing, fleet operators are not incentivized to adopt LR vehicles.
  • Electricity pricing structures should considered in the conversation about disruptive mobility.
Thank you for your time!