# Shared Autonomous Electric Mobility:

## Opportunities & Challenges

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# 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

Alleviates “range anxiety.”

Electric

Automated charging/fueling is easier to achieve w/ electric vehicles

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

High cost of automation technology incentivizes shared use.

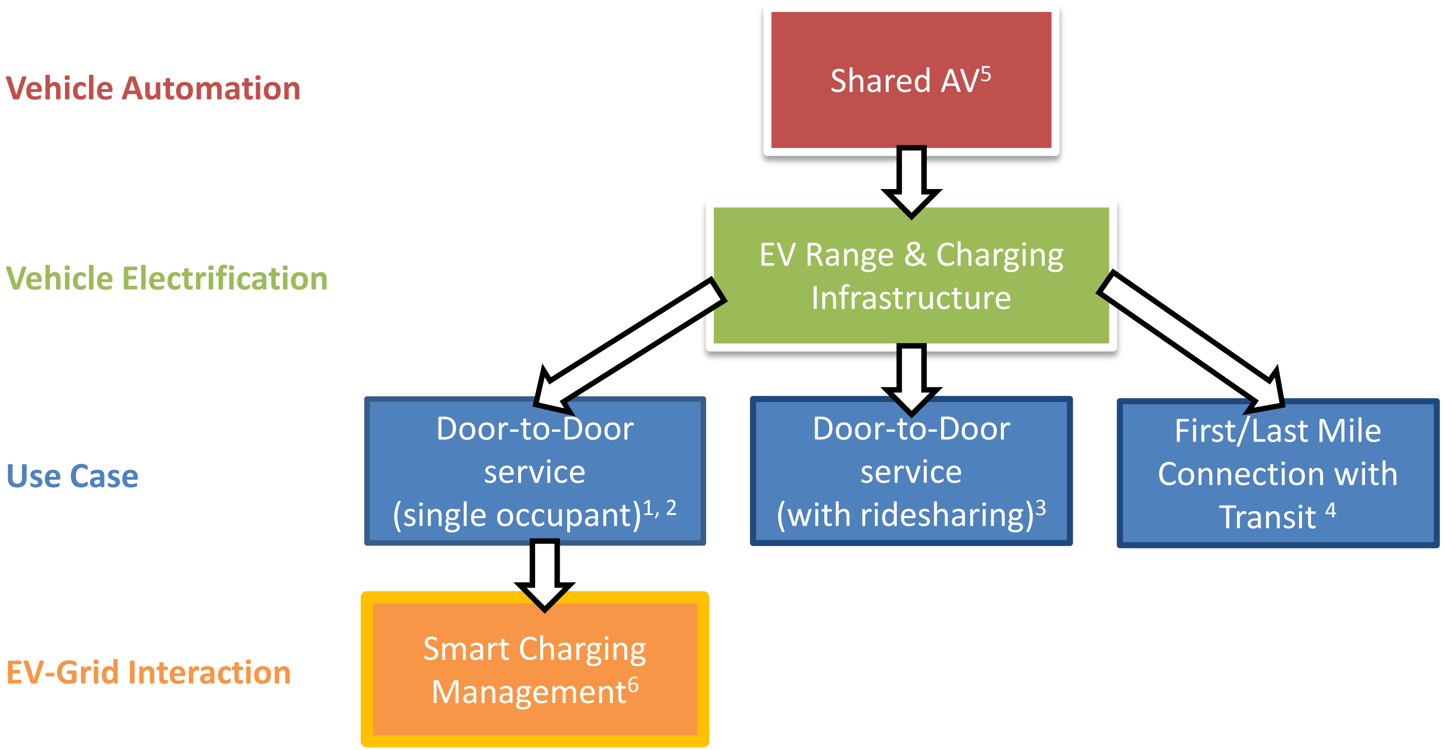
Accelerates EV adoption to meet urban air quality & transport emissions goals.

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

Shared

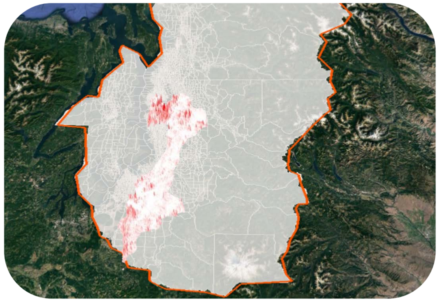
# Shared Autonomous Electric Vehicle

## Chen Research Group



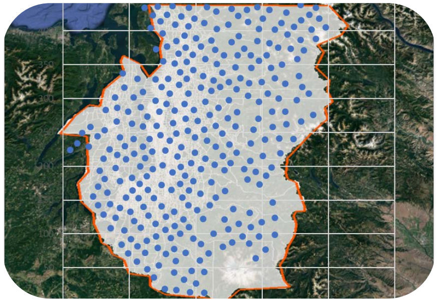

1. Chen, T.D, K. M. Kockelman & J.P. Hanna (2016) "Operations of a Shared, Autonomous, Electric Vehicle Fleet: Implications of Vehicle & Charging Infrastructure Decisions." *Transportation Research Part A: Policy and Practice* 94: 243-254.
2. Chen, T. D. & K.M. Kockelman (2016) "Management of a Shared Autonomous Electric Vehicle Fleet: Implications of Pricing Schemes." *Transportation Research Record* 2572: 37-46.
3. Farhan, J. & T.D. Chen (2018) "Impact of Ridesharing on Operational Efficiency of Shared Autonomous Electric Vehicle Fleet." *Transportation Research Part C: Emerging Technologies* 93: 310-321.
4. Farhan, J., T.D. Chen & Z. Zhang (2018) "Leveraging Shared Autonomous Electric Vehicles for First- and Last-Mile Mobility." Proceedings of the 97th Annual Meeting of the Transportation Research Board, January 2018, Washington, DC.
5. Hanna, J.P., M. Albert, T.D. Chen & P. Stone. (2016) "Minimum Cost Matching for Autonomous Carsharing." *International Federation of Automatic Control Papers On Line* 49-15: 254-259.
6. Zhang, Z. & T.D. Chen, "Smart Charging Management for Shared Autonomous Electric Vehicle Fleet: A Puget Sound Case Study," presented at the 98th Annual Meeting of the Transportation Research Board, January 2019, Washington, DC.

# SAEV Modeling Framework



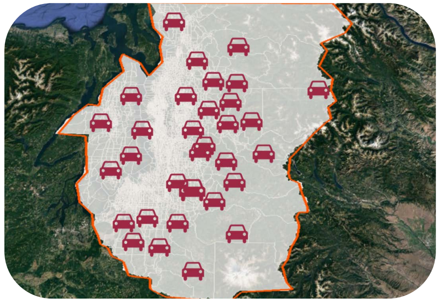
## Trip Generation

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



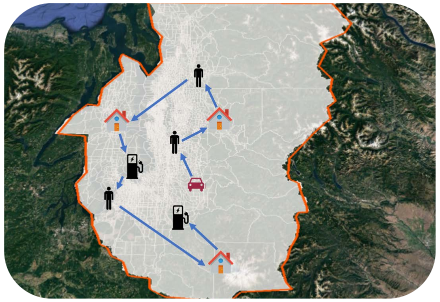
## Charging Station Generation

- Charging station site selection to ensure sufficient infrastructure coverage



## SAEV Fleet Generation

- Determine the necessary fleet size to serve travel demand

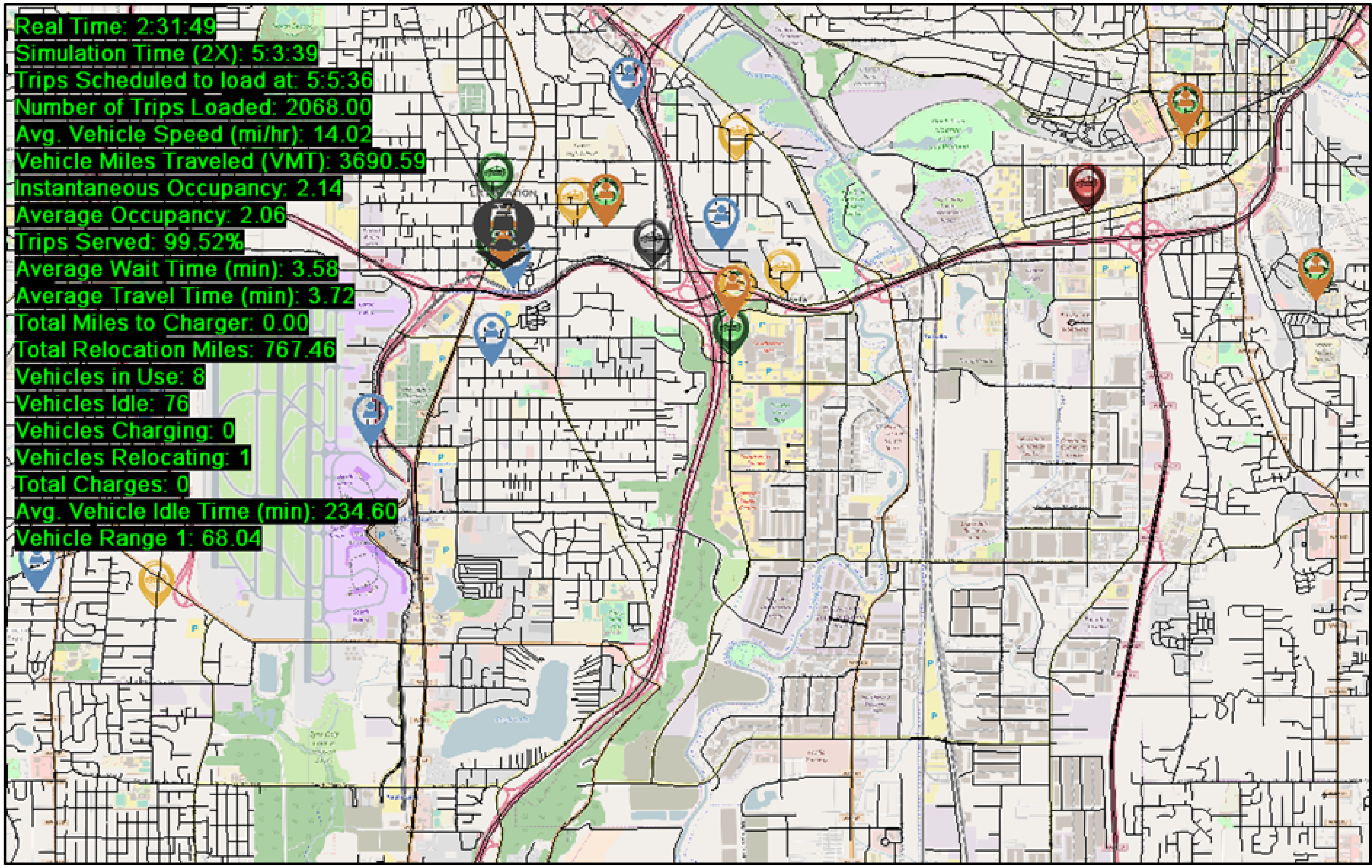


## Operation

- Continuous daily operation based on the station and fleet configuration

# SAEV Simulator Implementation

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



# 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

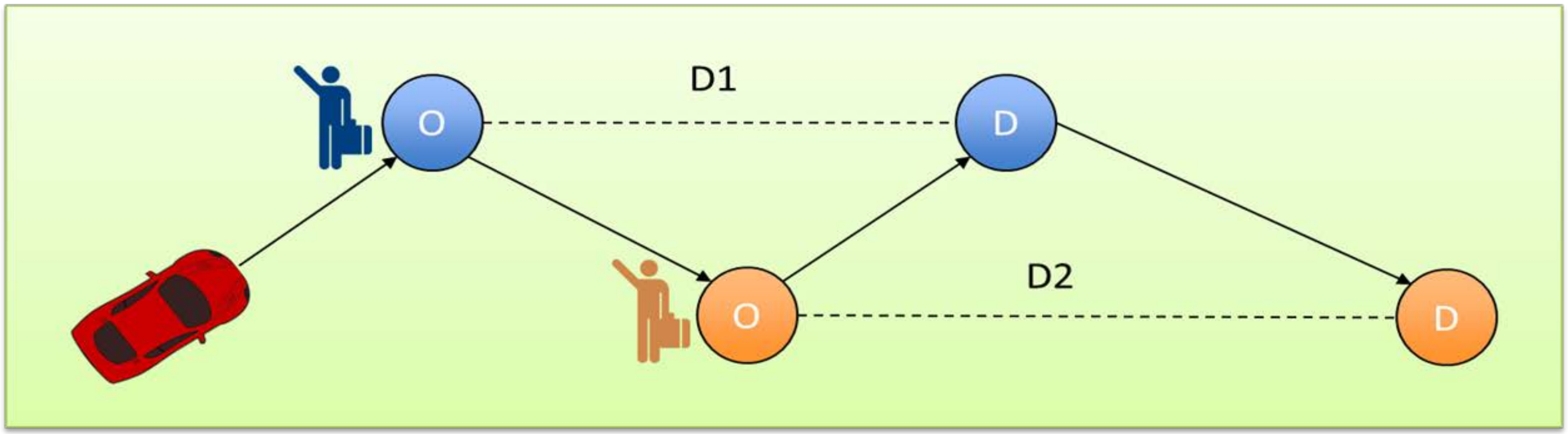
- Average energy efficiency: 0.33 kWh/mi
- *Accounts for 20% increase in energy consumption due to vehicle automation hardware and software*

# SAEV Model Assumptions

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

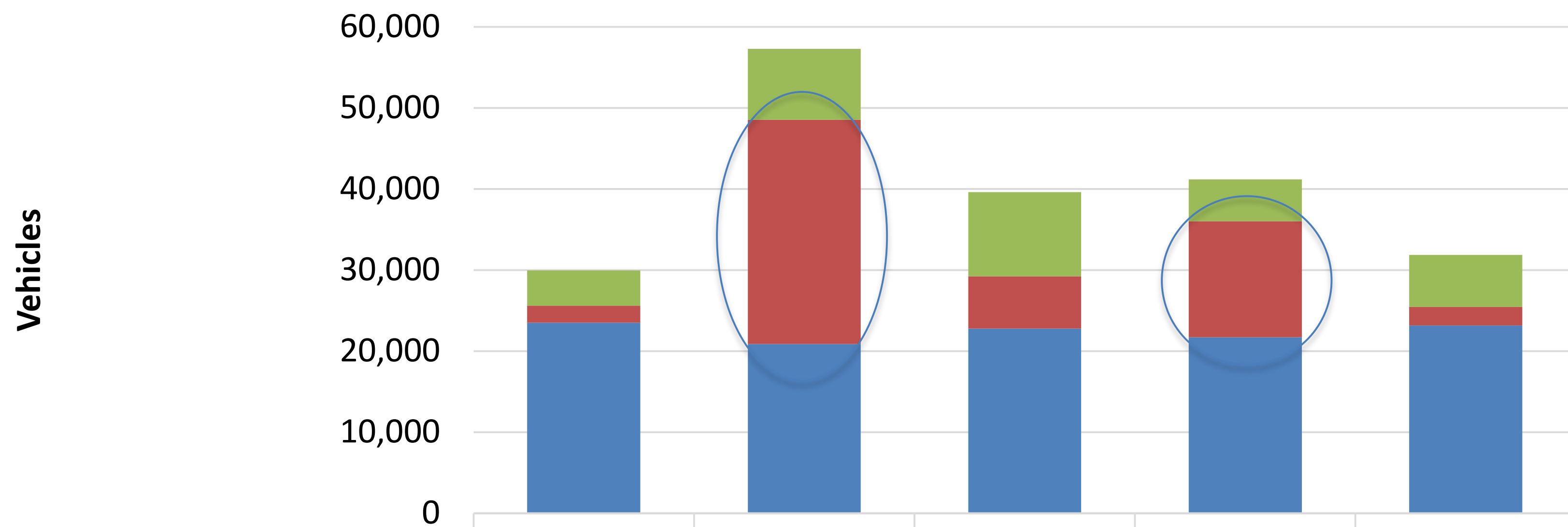
- Fleet serves 10% of a region’s travel demand
- Land use and travel behavior have not yet been influenced by SAEVs
- Charging station capacity is not explicitly modeled, only charging station locations

# SAEV Use Case: Door-to-Door Service




Case studies in Austin, Texas

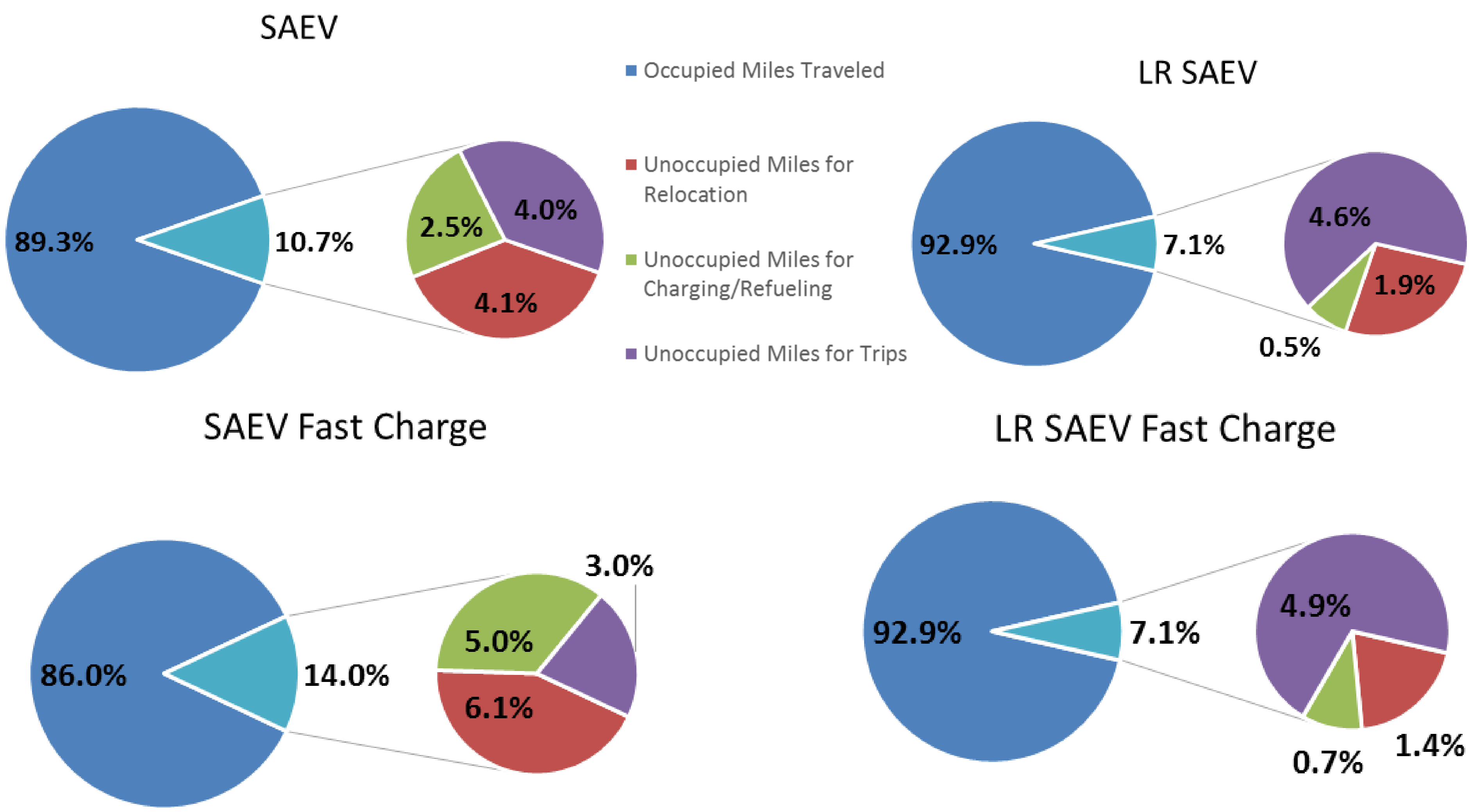
# Door-to-Door SAEV Service (Single Occupant):
## Fleet Size by Vehicle & Charging Infrastructure




| | SAV | SAEV | SAEV Fast Charge | LR SAEV | LR SAEV Fast Charge |
|---|---|---|---|---|---|
| Unused/Relocating Vehicles | 4339 | 8741 | 10359 | 5145 | 6408 |
| Charging Vehicles | 2085 | 27668 | 6459 | 14340 | 2288 |
| In Use Vehicles | 23515 | 20869 | 22774 | 21693 | 23162 |

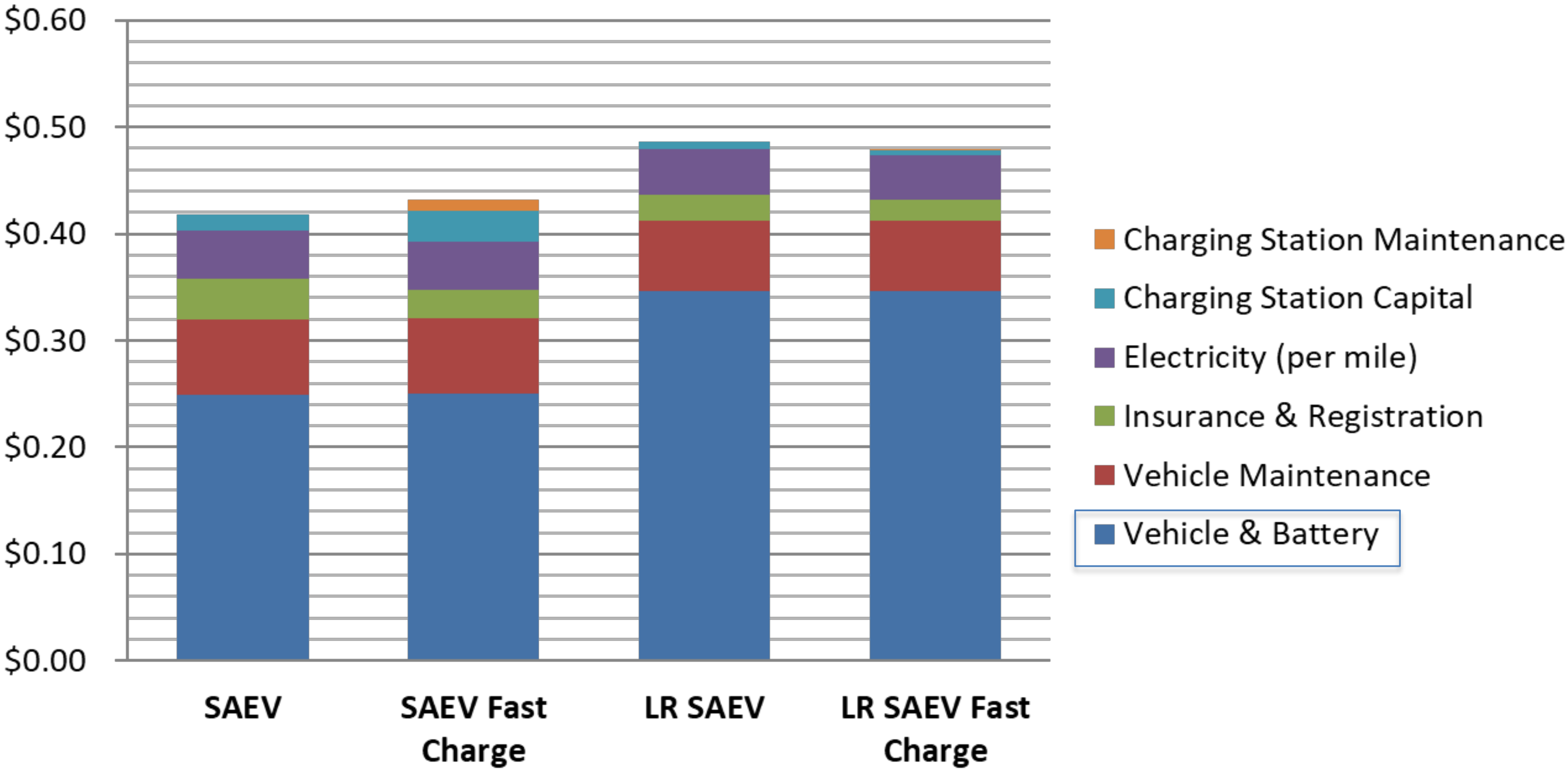
- **Fast charging** infrastructure & longer **EV range** reduces required fleet size.
- Each SAEV can **serve 11 to 21 trips per day**, equivalent to **replacing 3.7 to 6.8 privately owned vehicles**. (SAVs serve, on average, 22 trips/day)

# Door-to-Door SAEV Service (Single Occupant):
# "Empty" Miles Traveled



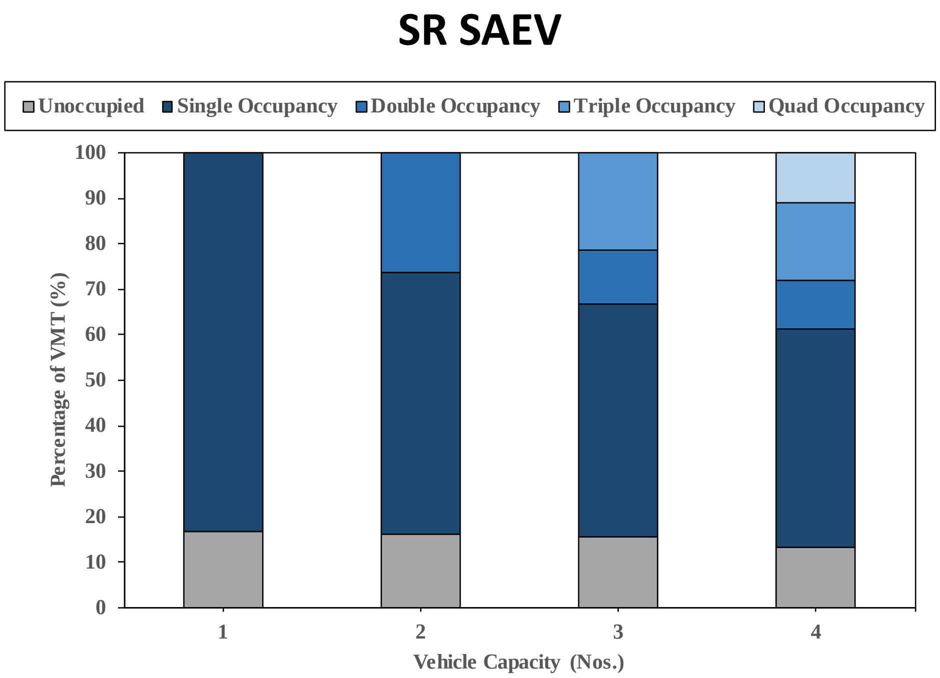

- **"Empty" VMT** constitutes **7 to 14%** of all miles traveled. (For SAVs, "empty" VMT is 6.6%)
- **Short range** SAEVs incur more **zero occupant miles** due to more trips for recharging.

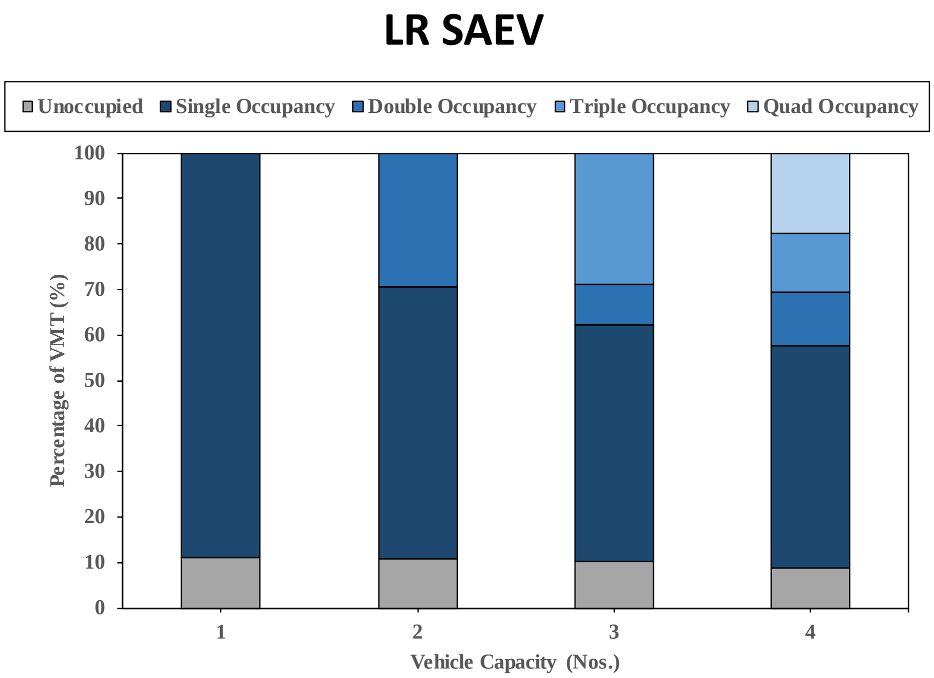
# Door-to-Door SAEV Service (Single Occupant):
## Operational Cost Per Occupied-Mile Traveled




- **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

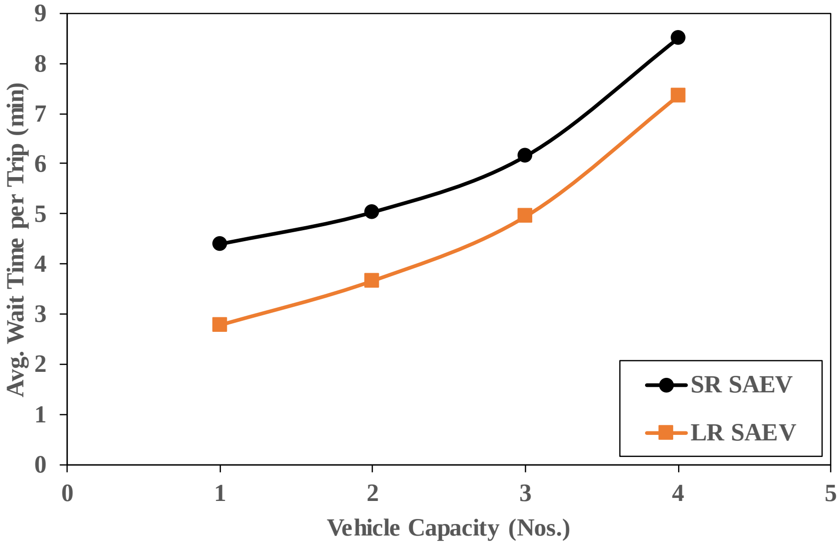


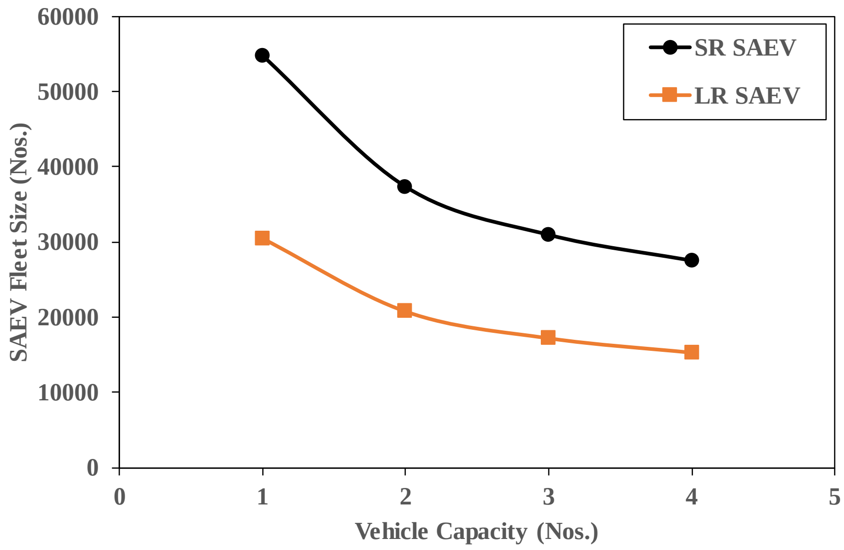



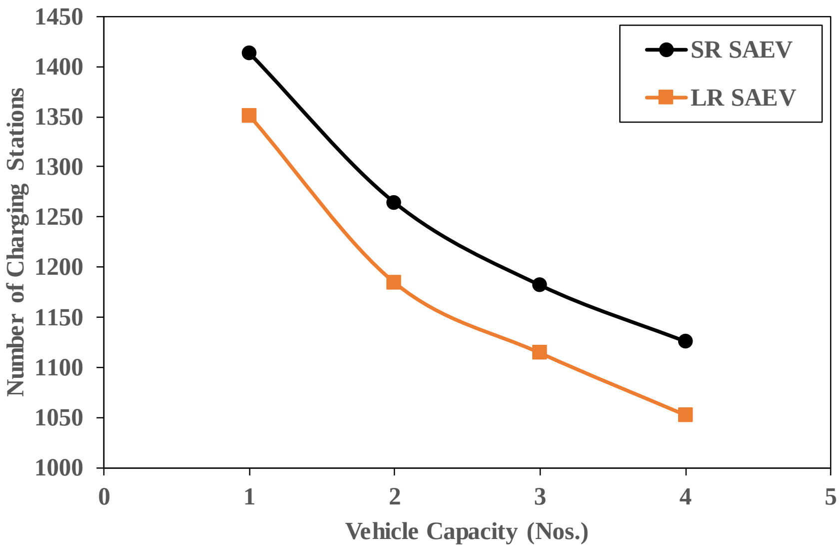

- **"Empty" VMT** comprises 13-16% of total VMT for SR SAEV scenario and 9-11% for LR SAEV scenario.
- Assuming all travelers are willing to participate in ridesharing, about **35% of all VMT** include at **least two passengers**.
- One **SAEV with dynamic ridesharing** can **replace 8 to 13 privately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

# 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**.

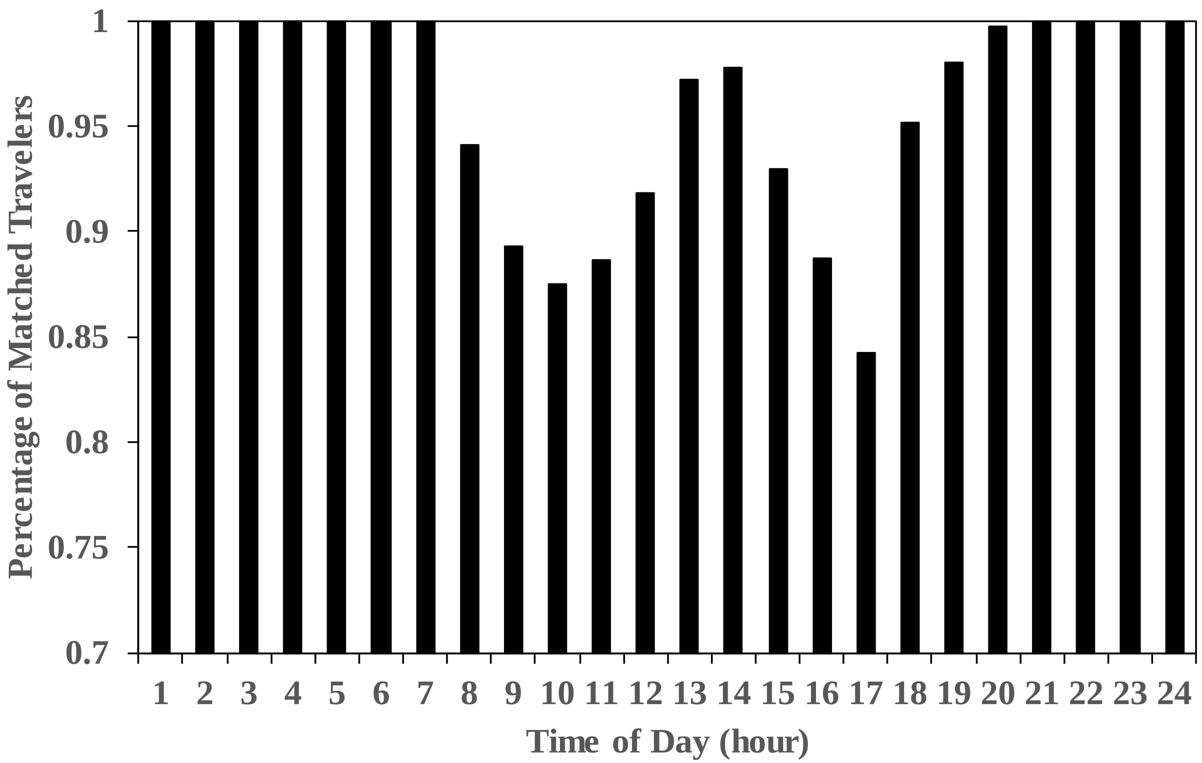


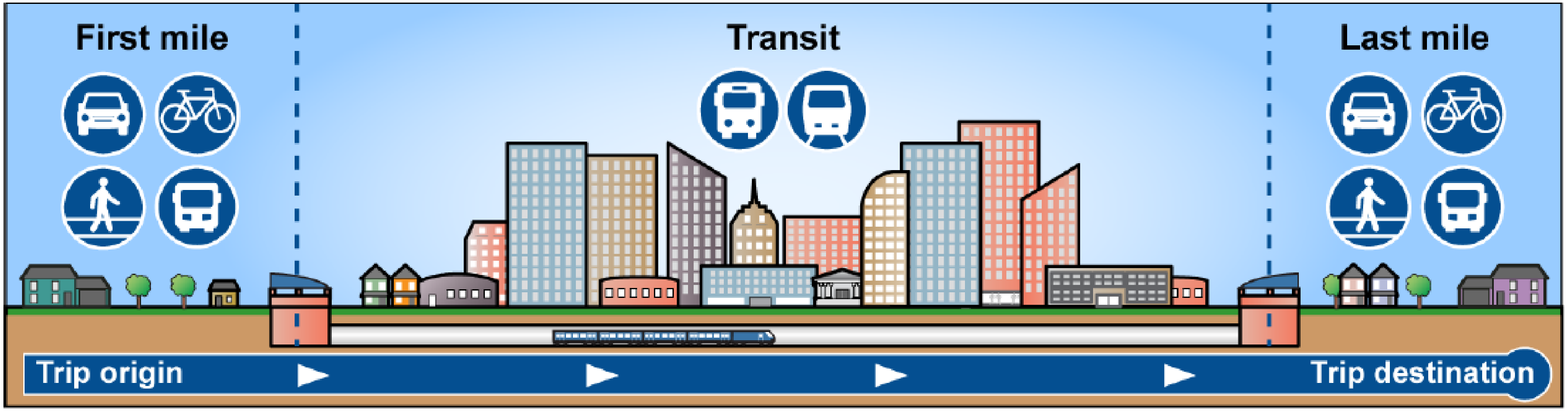
# SAEV Door-to-Door Service w/ Dynamic Ridesharing

- 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%.




**Likelihood of Finding a SAEV by Time of Day (SR SAEV)**

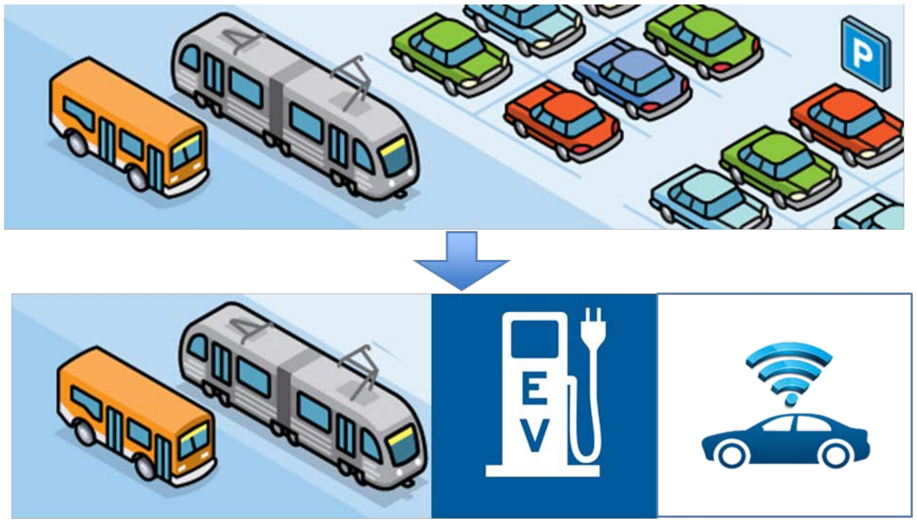
# SAEV Use Case: First/Last Mile Connection



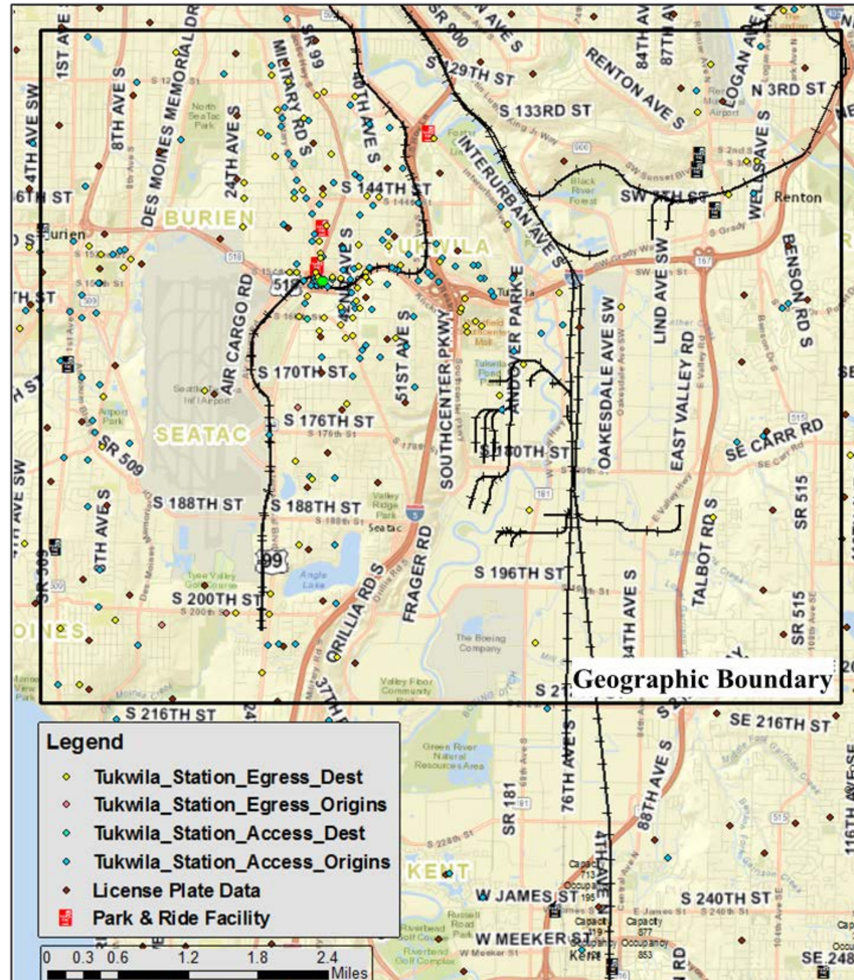

Case study in Seattle, Washington

# 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.



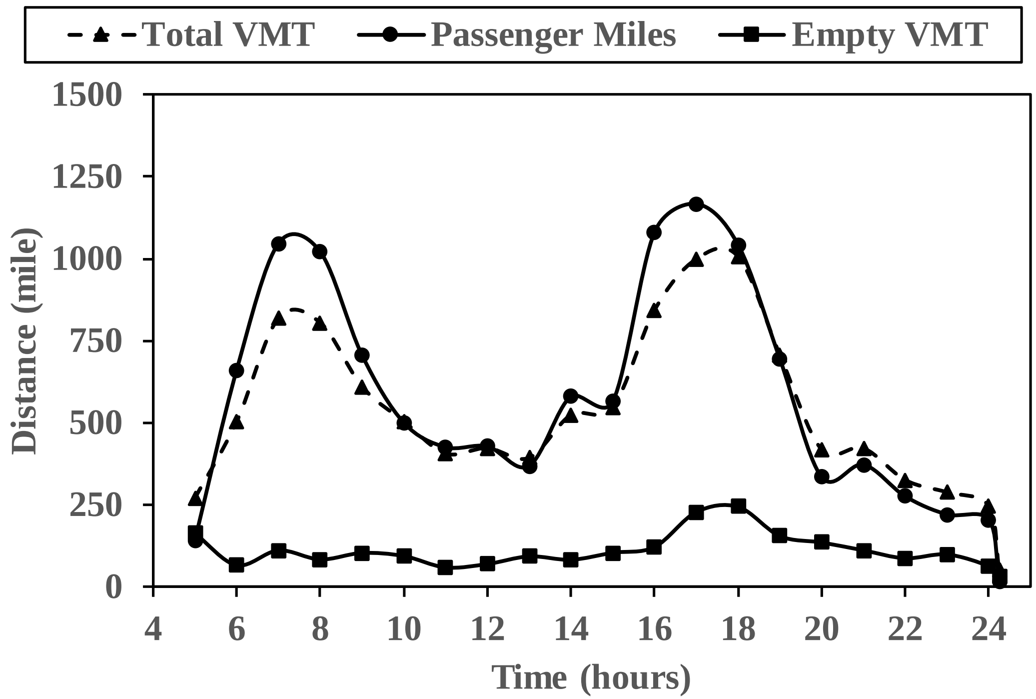

Park and Ride Lot replaced by Charging Station




Case study at Tukwila Light Rail Station in Seattle, Washington

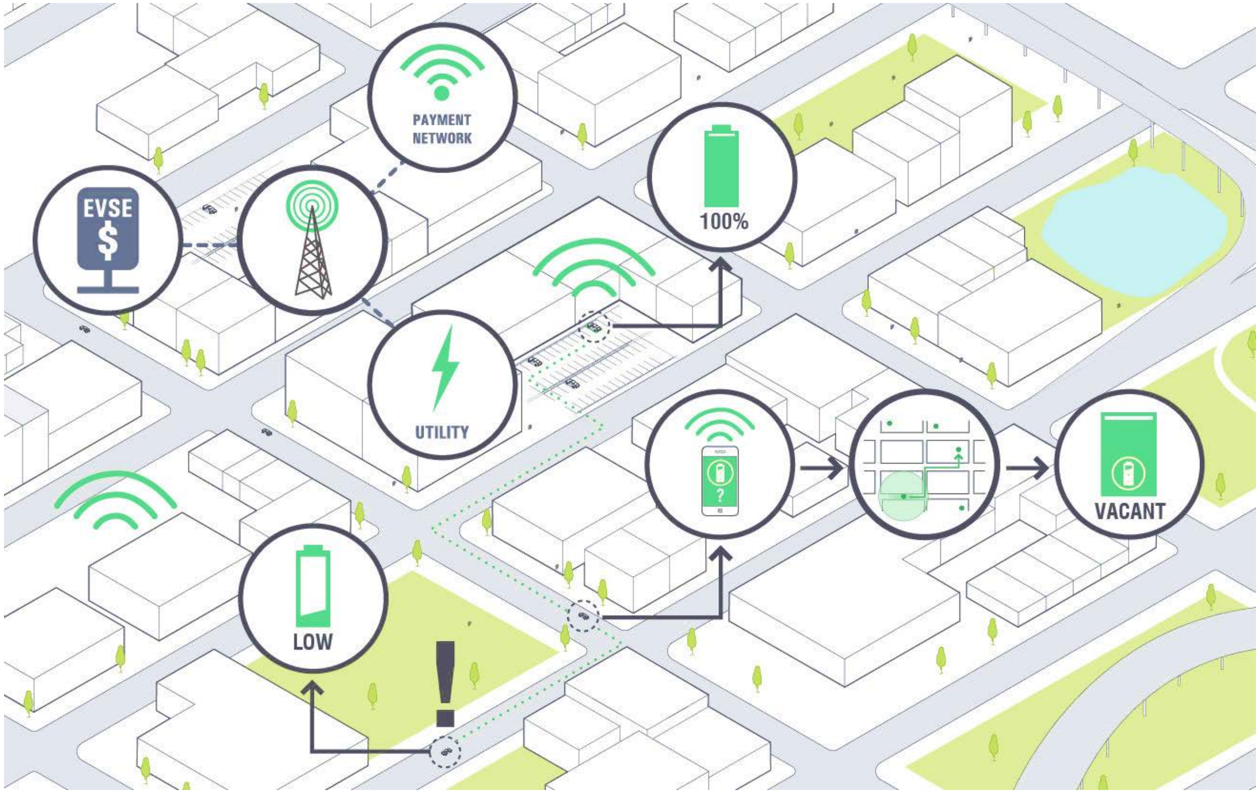
- 2016 survey of rider origin-destinations
- Hourly boarding & alighting data

# SAEVs for First/Last Mile Connection




- **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.

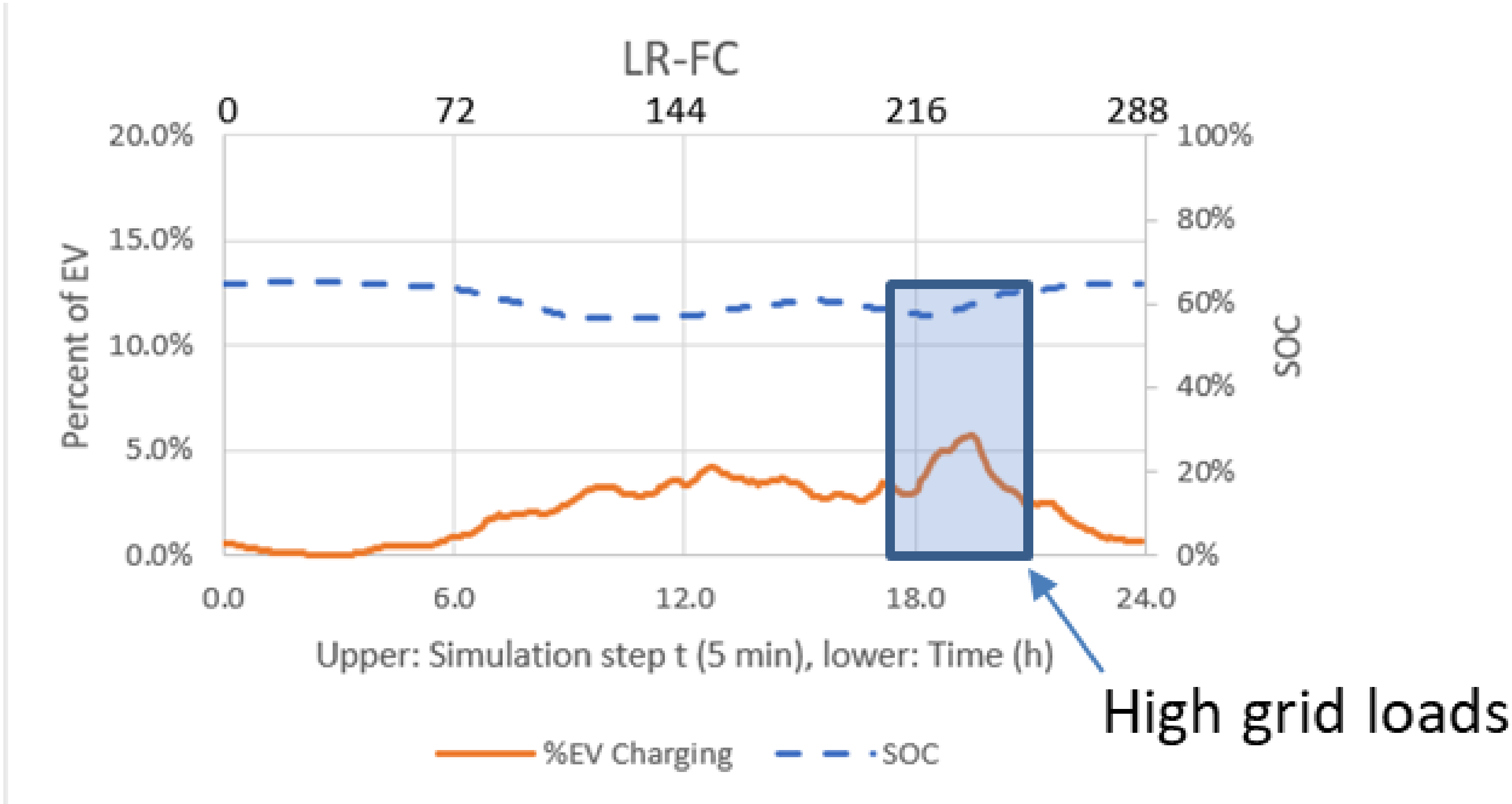
# SAEV-Grid Interaction




Case study in Seattle, Washington

# SAEV-Grid Interaction

## Unmanaged SAEV Charging



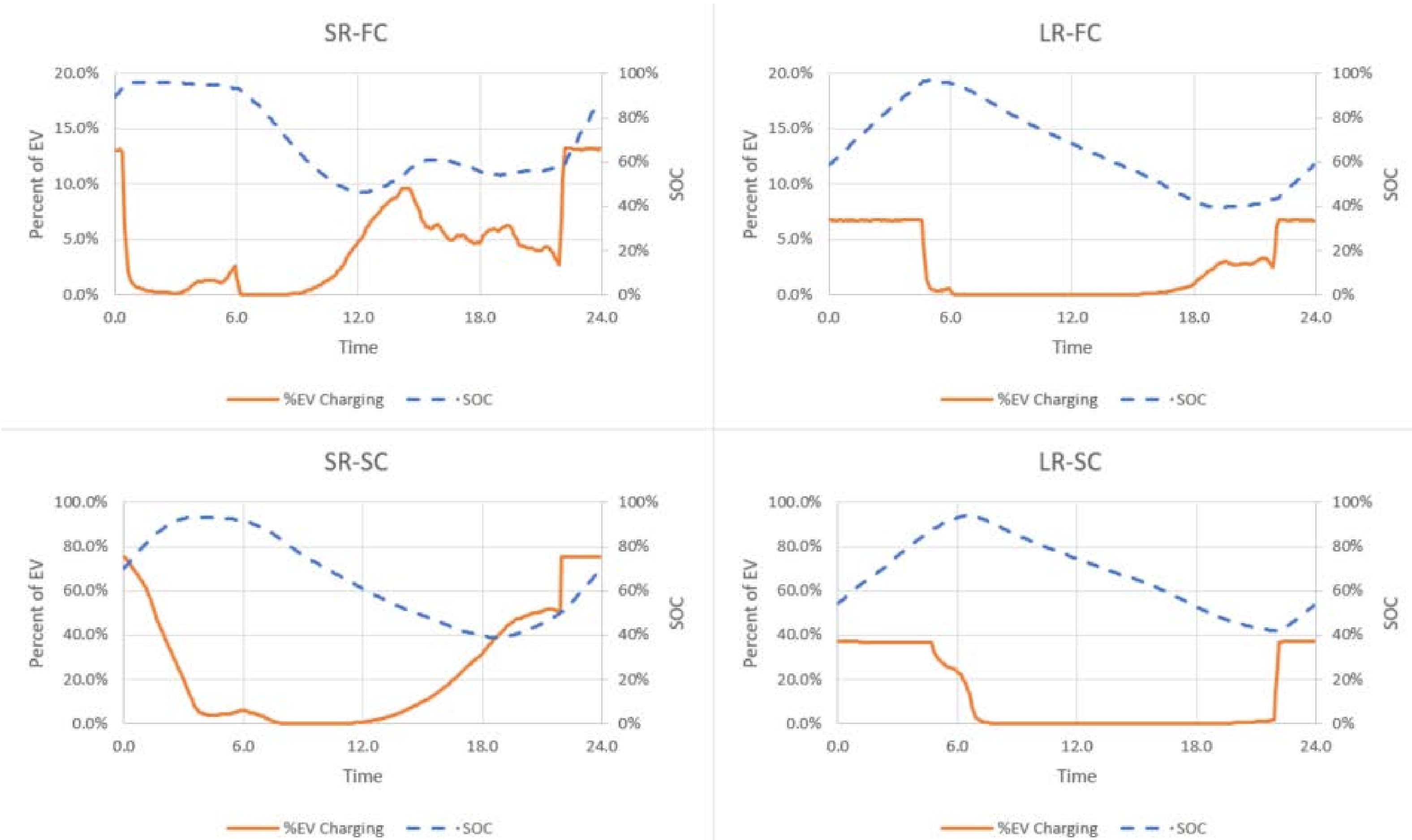

Charging "as needed" minimizes SAEV "empty" travel distance for charging, but exhibits **peak charging periods** which coincide with **existing peak hours of electricity use**.

# 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

# SAEV-Grid Interaction

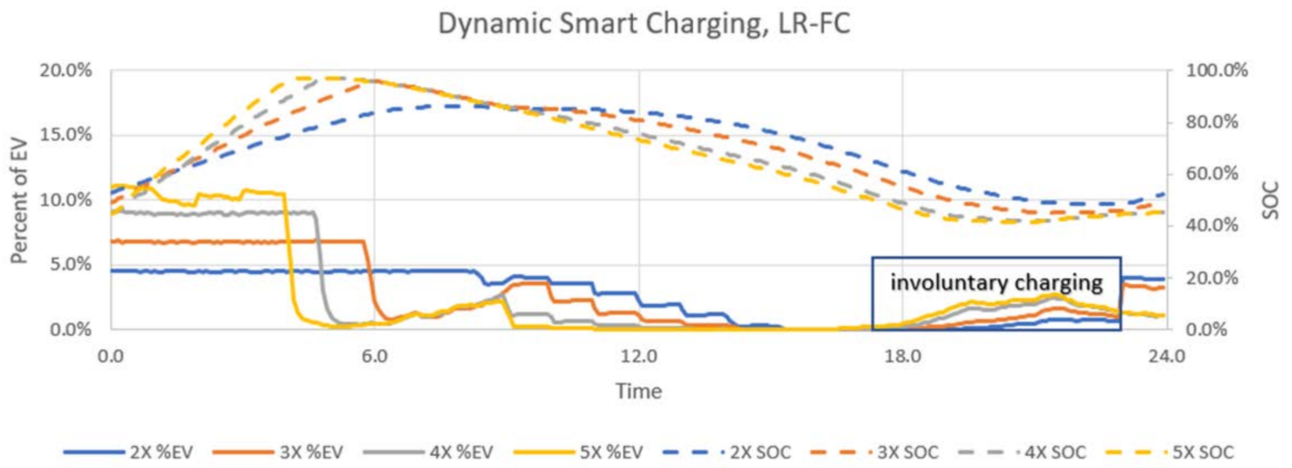
## SAEV Smart Charging under TOU Pricing

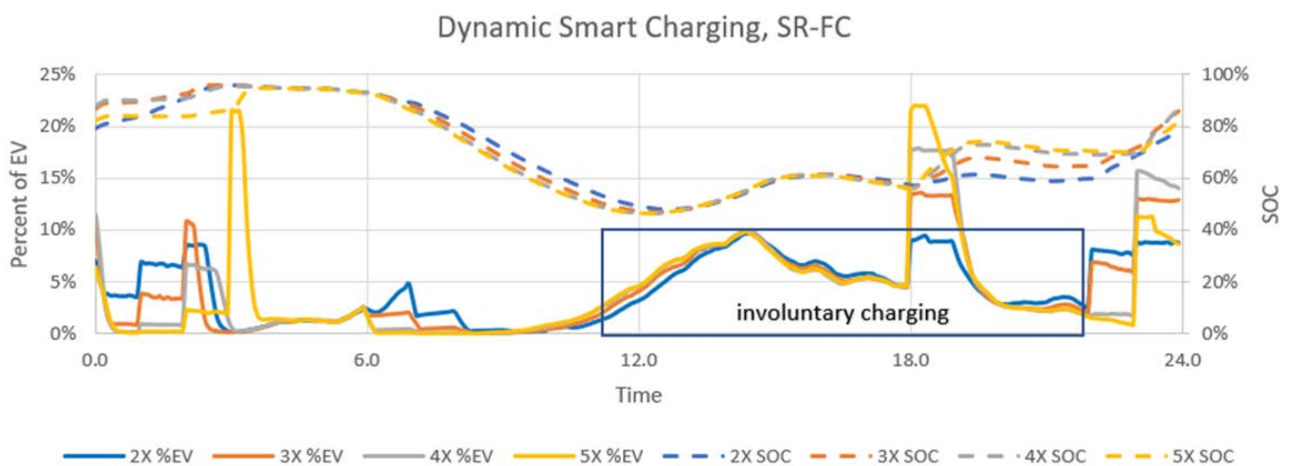



With increased battery capacity, **LR vehicles** exhibit superior ability to **avoid charging on-peak**. Compared to unmanaged charging, electricity costs can reduce 10% (SR SAEVs) to 34% (LR SAEVs).

# SAEV-Grid Interaction

## SAEV Smart Charging under Real Time Pricing




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!

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