REGIONAL OPERATIONS OF SHARED AUTONOMOUS VEHICLES (SAVs)

– WITH & WITHOUT DYNAMIC RIDESHARING (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.

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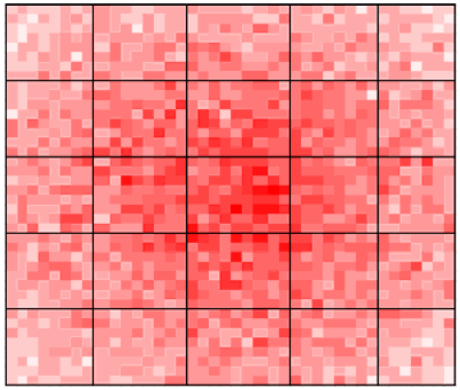
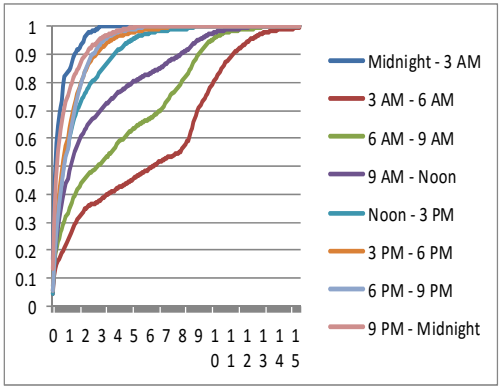
Our First Agent-Based **Model Design**

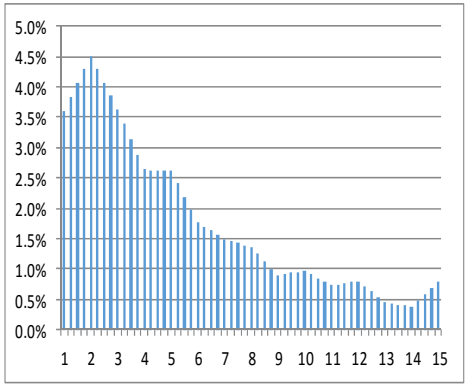
- Grid-based 10 mi x 10 mi urban area with **0.25-sq. mile zones**.
- **Trip generation**:
  - Poisson-based PK & OP counts for **trip generation**, **every 5 minutes**.
  - Higher **trip production & attraction** rates closer to city center.
  - **Mostly round-trip** travel, with 78% travelers returning via SAVs.
  - Random **departure times & trip distances** (2009 NHTS).
- SAVs travel at **fixed speeds**, with **5 min.** intervals.



Trip Generation



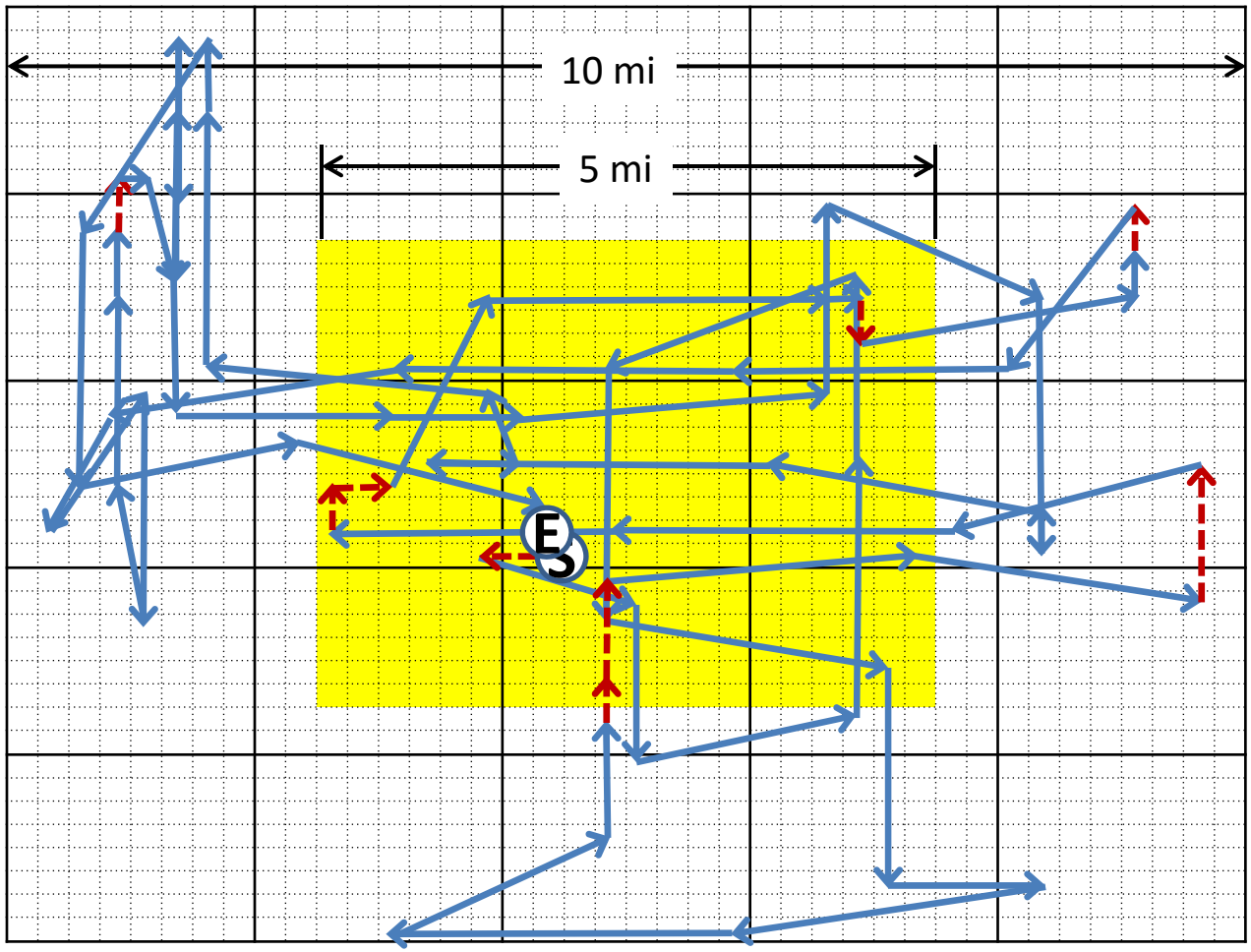
Dwell Times (hrs.)



Trip Distances (mi.)

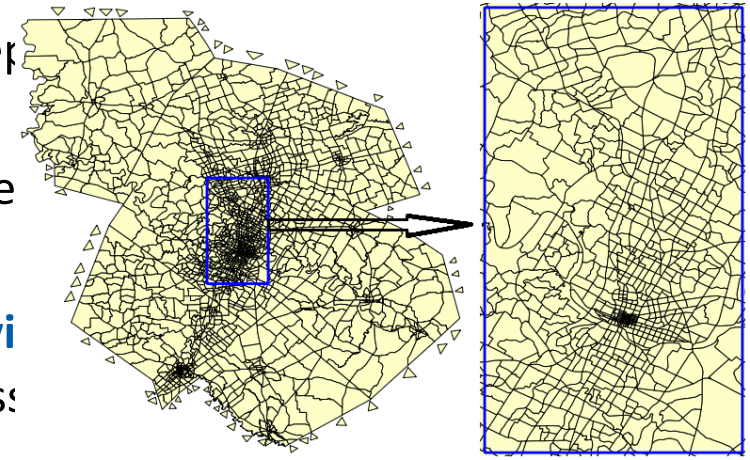
Example: One SAV's 24-hour Journey

- **Urban Core**
  Higher AM Trip Attraction
- **Outer Periphery**
  Higher PM Trip Attraction
- **Blue Arrows**
  Serving Riders
- **Red Arrows**
  SAV Relocation



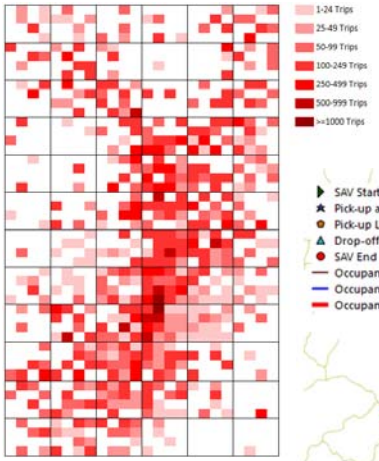
Town & City Results

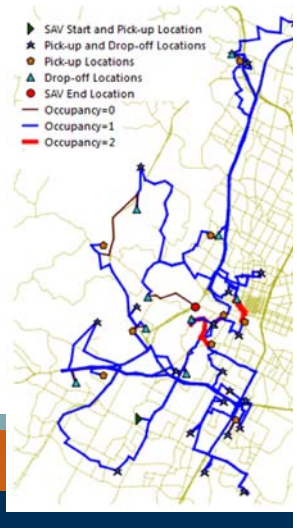
- **100 days simulated**, with **each SAV** consistently rep
  9 to 13 household vehicles.
- Avg. **wait time ≈ 2.8 min, but 11% new/induced** (e
  vehicle) **VKT.**
- **5% to 50%** (GHG vs. VOCs) life-cycle **emissions savi**
  thanks to **smaller vehicles,** fewer **cold starts**, & less
  parking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



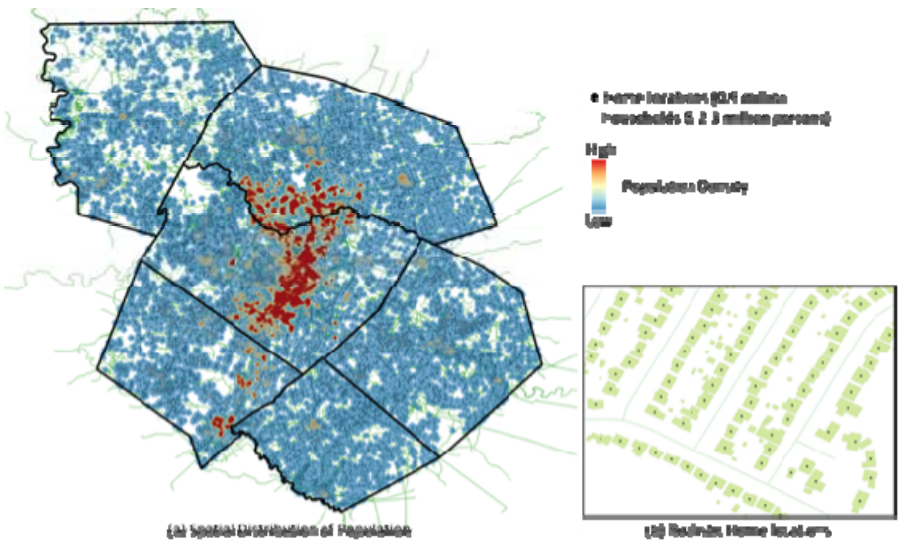
*Extending this to **12 mi x 24 mi central Austin**, with actual network & trip patterns delivers similar results…*

- **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.

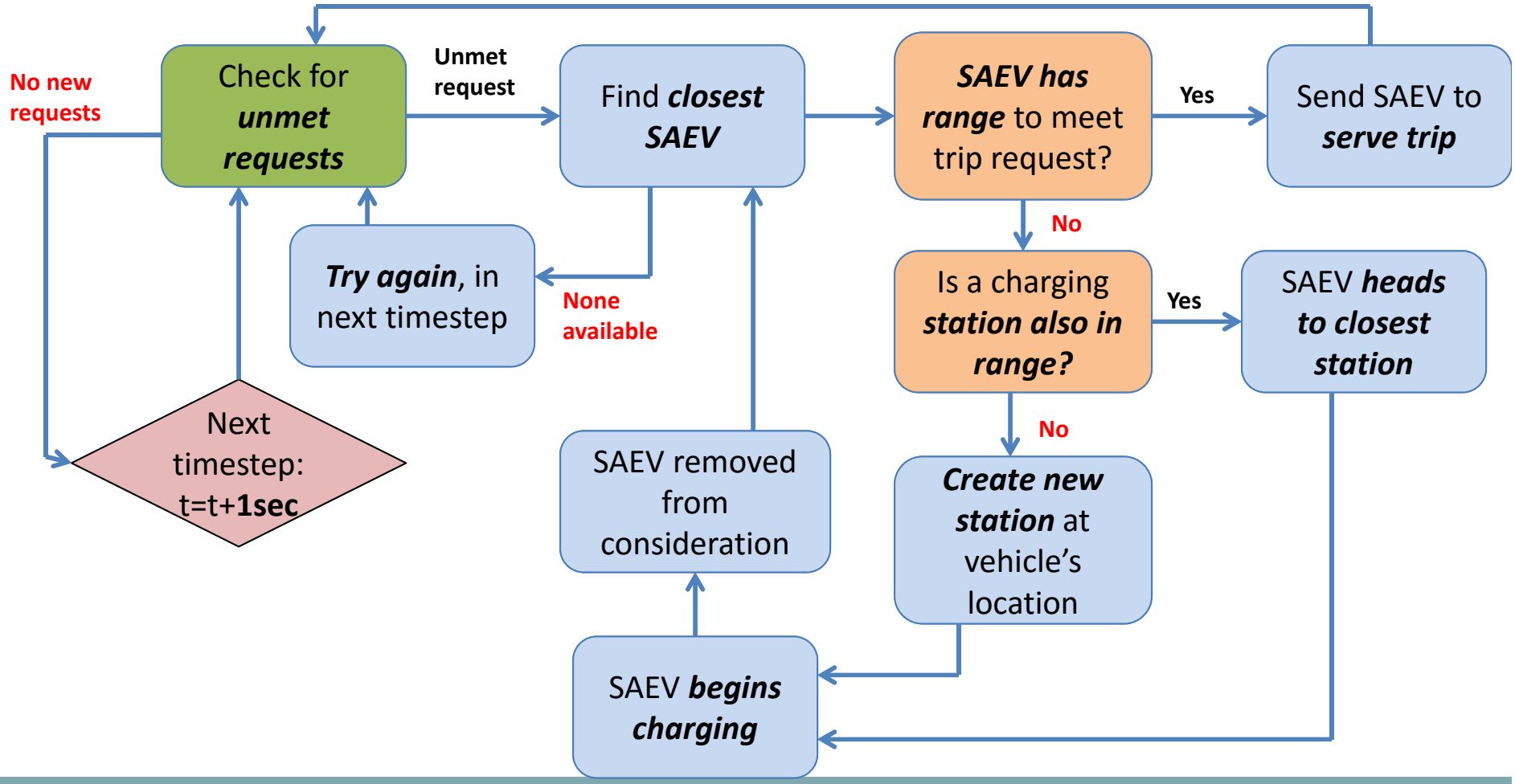




What if… SAVs Serve the Entire Region? & Are SAElectricVs?

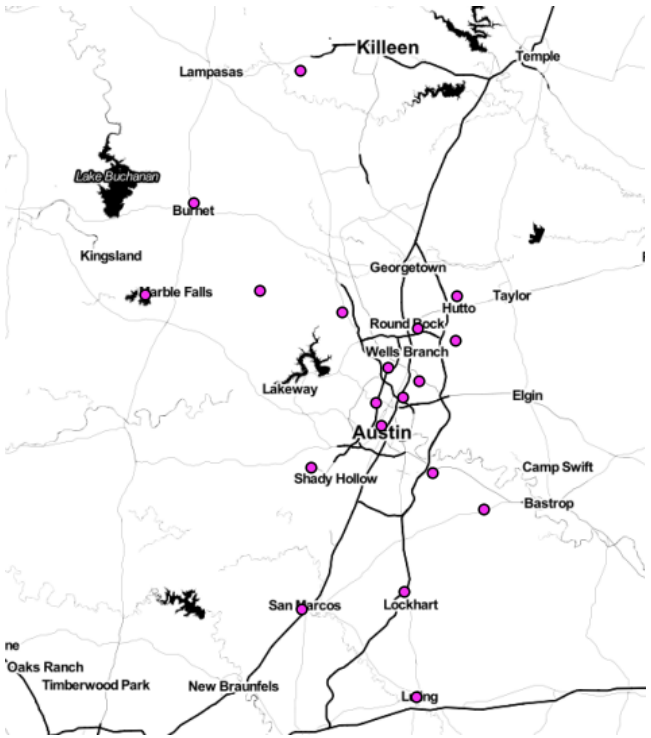


Chaging Station Generation via 30-day Initial Run



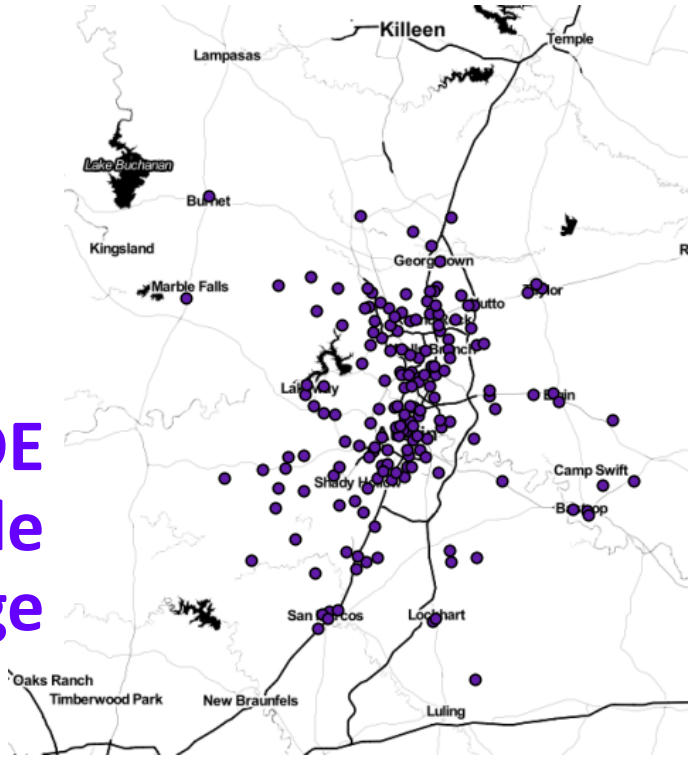
Example Station Locations

- **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

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

- **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

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

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).

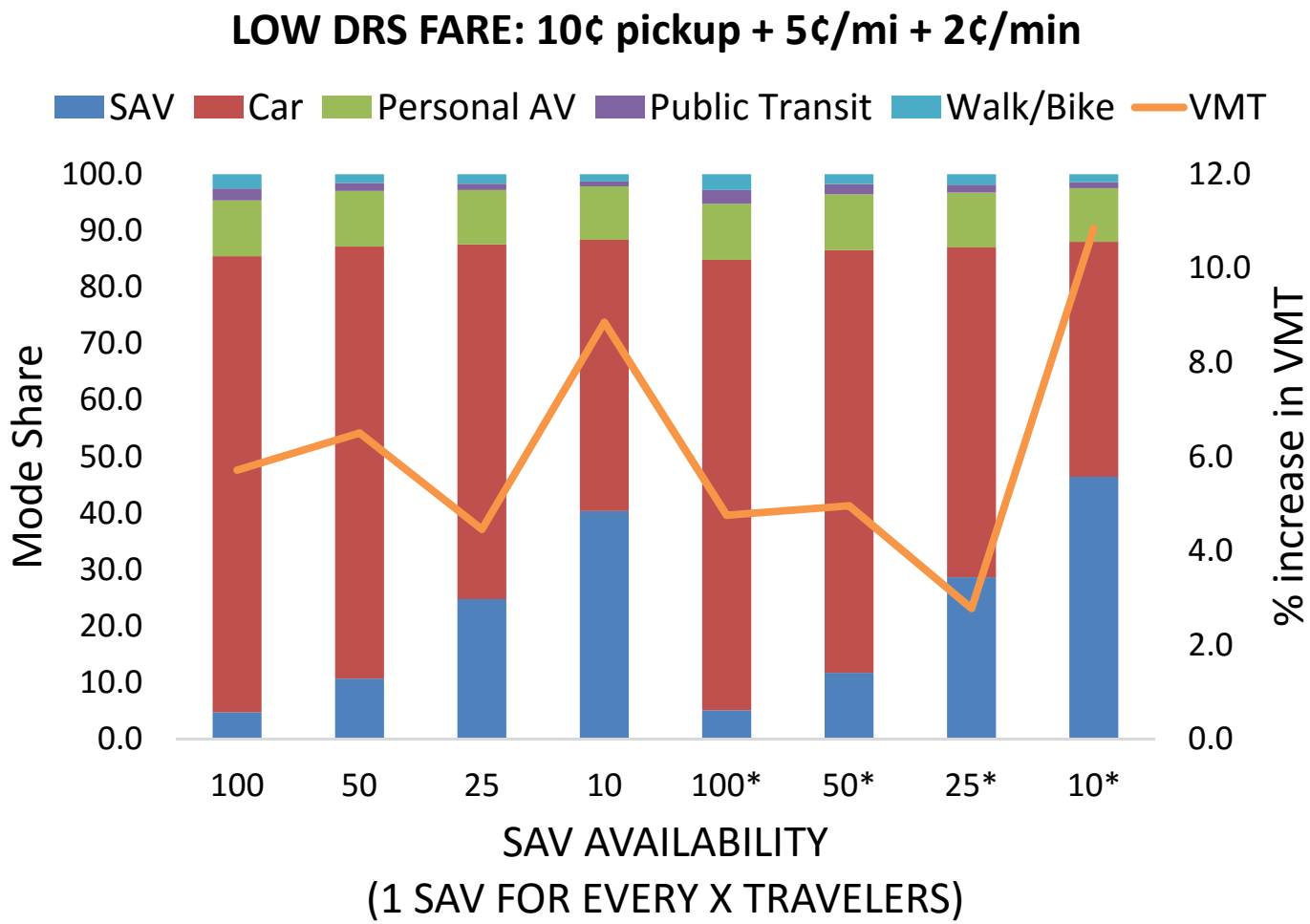
+10% from **shift away from airline** travel on trips < 800 km.

Perhaps +10% from **land use changes**? (sprawl)

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

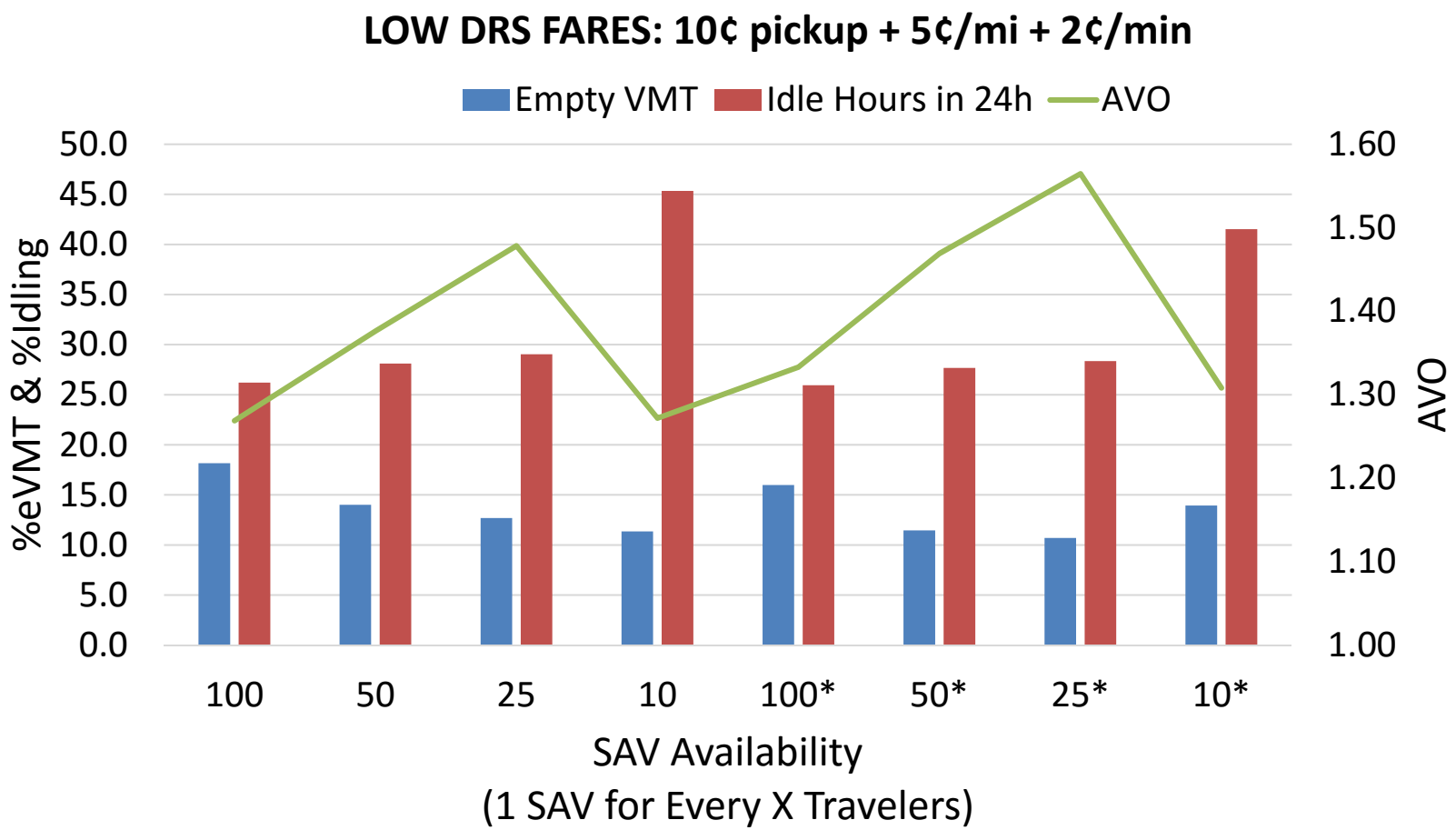
Central Question: Can **tolling strategies** keep traffic moving while improving social welfare?

Regional Results: **Mode Splits + VMT**



* with tolls of 5¢/min delay

%Empty VMT, %Idling, & Avg Veh Occupancy



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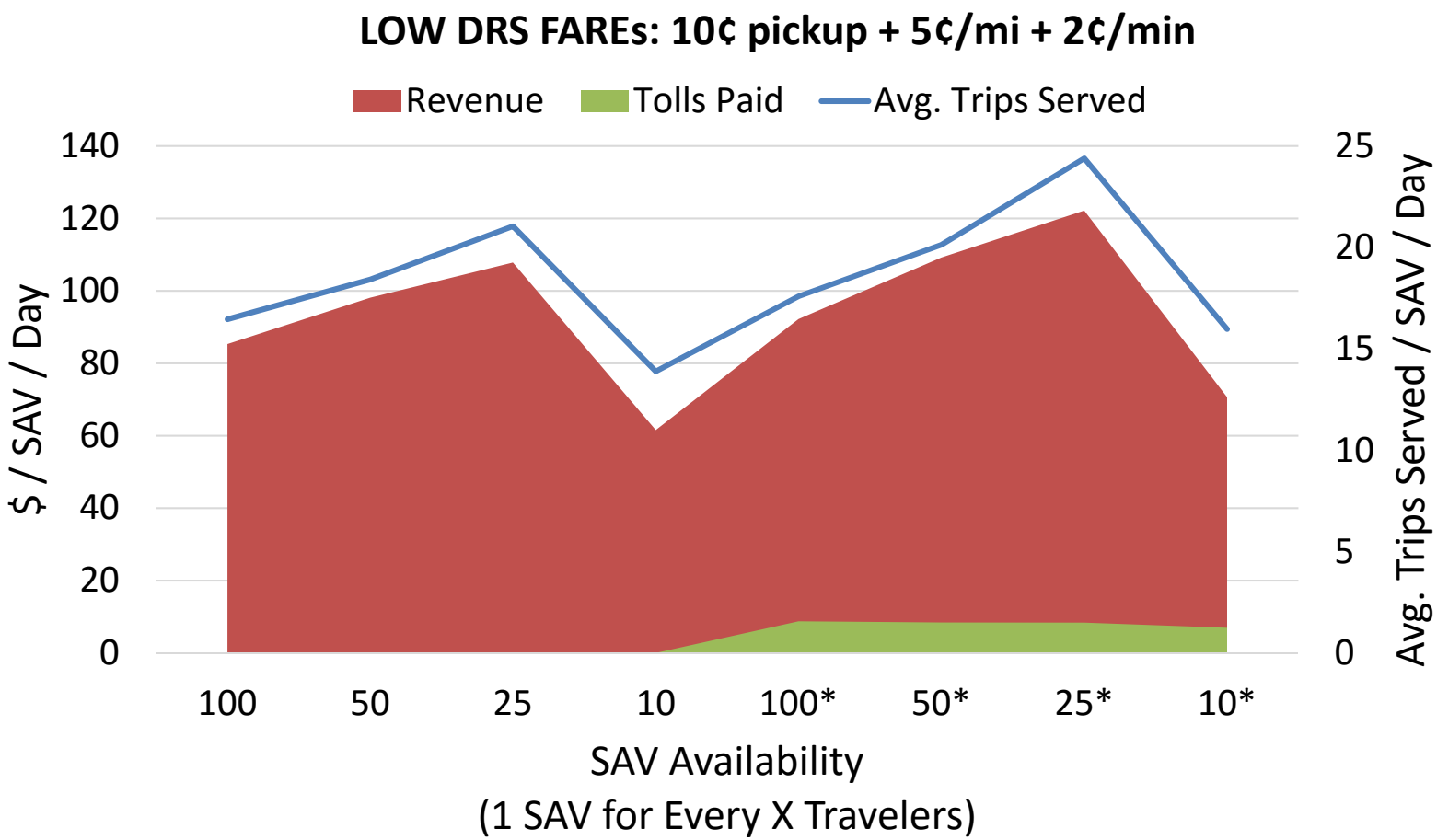
Profits + Toll Revenues + Trips/day/SAV



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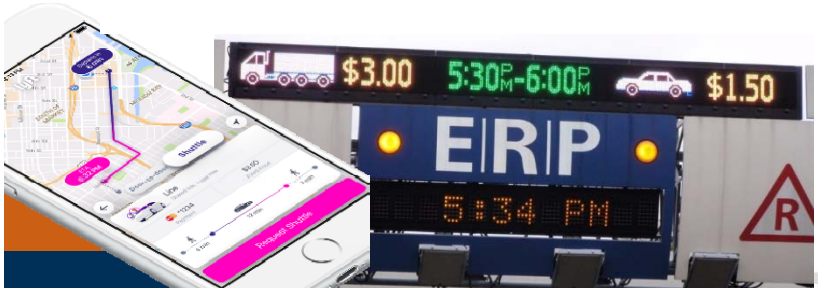
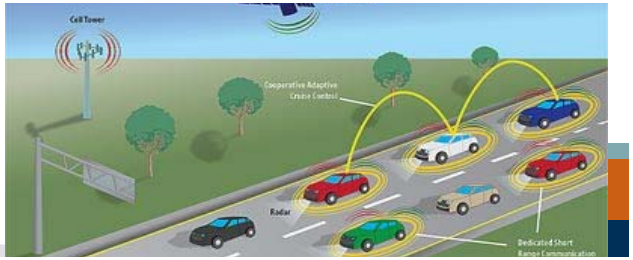
In Conclusion…

- **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)

- Lee, J., & Kockelman, K. 2019. **Development of Traffic-based Congestion Pricing & Its Application to Automated Vehicles**. *Transportation Research Record* 2673 (6): 536-547 .
- Simoni, M.D., Kockelman, K., Gurumurthy, K.M. & Bischoff, J. 2019. **Congestion Pricing in a World of Self-Driving Vehicles: An Analysis of Different Strategies in Alternative Future Scenarios**. *Transportation Research Part C* 98: 167-185.
- Gurumurthy, K.M., Kockelman, K. & Simoni, M.D. 2019. **Benefits & Costs of Ride-Sharing in Shared Automated Vehicles Across Austin, Texas: Opportunities For Congestion Pricing**. *Transportation Research Record* 2673 (6): 548-556.