Evaluation of impacts of CAV on the transportation system in Southern California through an activity-based approach

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Agenda

1. Background
2. State of the Art & Practice
3. Methodology
4. Research Findings & Conclusion
5. Dynamic Traffic Assignment

Background

Connected and Automated Vehicle (CAV)

- Connected Vehicles are vehicles that can communicate with other vehicles, infrastructure and devices.
- Automated Vehicles are vehicles that can operate with little to no human assistance.

Big Moves in the CAV Industry and Governments/Agencies

- Waymo officially started its commercial self-driving-car service in the suburbs of Phoenix in 2018. Other companies also include Argo AI, Cruise, and self-driving trucks from TuSimple, etc.
- The U.S. DOT issued Federal Automated Vehicles Policy in September 2016, and as of spring 2019, 44 states have proposed, and 30 states have enacted legislation pertaining to autonomous vehicles.

State of the Art & Practice

Transportation Demand Forecasting in CAV Era

- Potential Impacts of CAVs on ABM in Seattle, WA - Childress et al (2015)
- Impacts of intra-household shared CAV on ABM in the Chicago sub-area – Xu et al (2019)
- Incorporating features of CAVs in ABM for Columbus, OH – Vyas et al (2019)

Research Gaps

- Short of CAV related data or CAV preference data
- Unable to capture impacts on activity generation
- Not applicable for large scale models

Problem Statement

Our research aims to explore the changing trend of both travel demand and supply sides in the era of CAV and evaluate the impacts on transportation systems.

Research Goal

- The project aims to develop planning-level analysis tools based on existing models to support CAV-related decision-making for MPOs and other public agencies.

Contributions

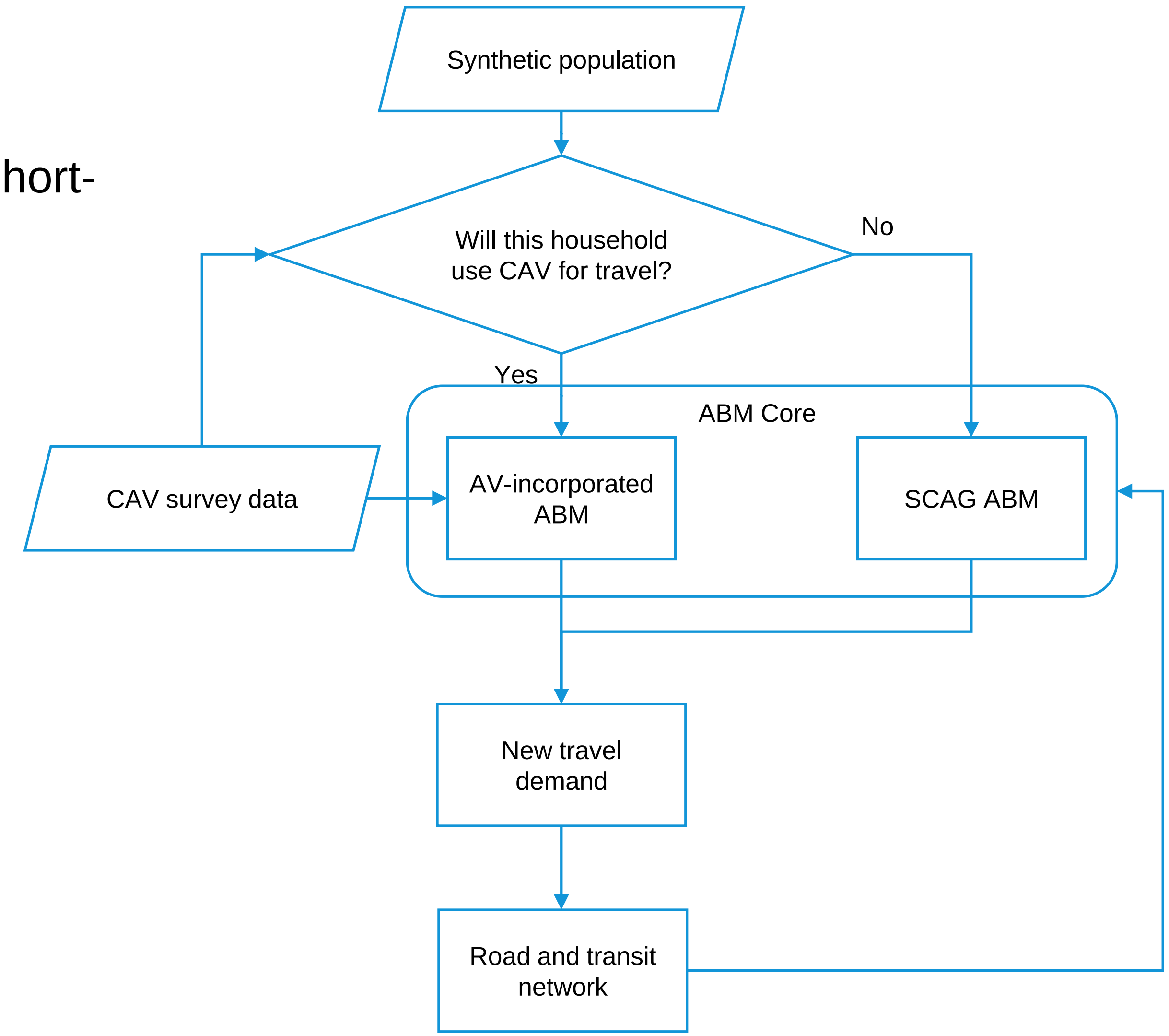
- Collected people's intent to use CAV in Southern California, and their activity-related preferences
- Incorporated behavior changes in the SCAG ABM framework, from long term to short term
- Integrated CAV ABM with the capacity enhanced traffic assignment model
- Evaluated travel demand management (TDM) strategies under CAV scenarios and provided policy recommendations

Methodology

We adopted an activity-based approach which incorporates CAV features from long-term choice to short-term choice.

- Demand
  - CAV Survey
  - SCAG ABM update
    - Long-term: Work arrangement
    - Medium-term: CAV ownership
    - Short-term: Activity frequency, mode choice
- Supply
  - Roadway capacity enhancement

Integration of survey data and travel demand model



Methodology

CAV Survey

An online **Stated Preference** survey was designed and distributed to collect people's intent to use CAV in their daily travels and activity-related changes due to CAV.

- Two-stage survey
  - CAV choice: ask questions about people's intent to use CAV and their demographic information, 687 valid responses collected
  - Activity choice: for CAV users only, ask questions about changes in their daily activity choices, 675 valid responses collected
- Multiple control attributes
  - Household size/income/number of vehicles
  - Personal age/education attainment/work status

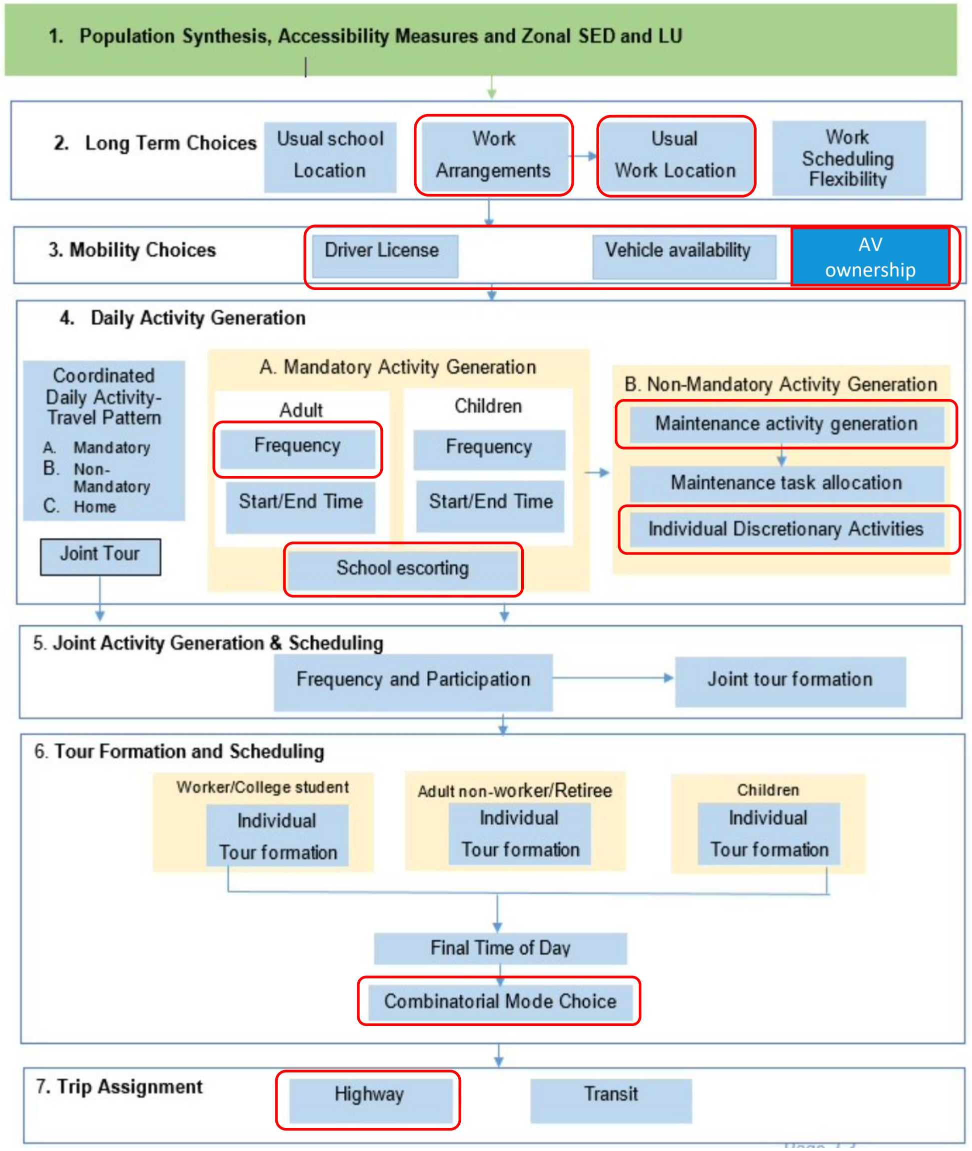
Comparison of data collected and quota from SCAG model

Age	Quota	Data
16~17	4.9%	2.9%
18~24	14.3%	14.3%
25~39	37.0%	34.4%
40~64	29.9%	30.1%
65+	14.0%	18.3%

Methodology

SCAG ABM Update

- Developed upon SCAG ABM framework
- Re-calibrate existing sub-models and develop new sub-models with new CAV preference data
- Incorporated both private and shared CAV in the mode choice model



SCAG ABM System Design (source: 2016 Regional Travel Demand Model and Model Validation)

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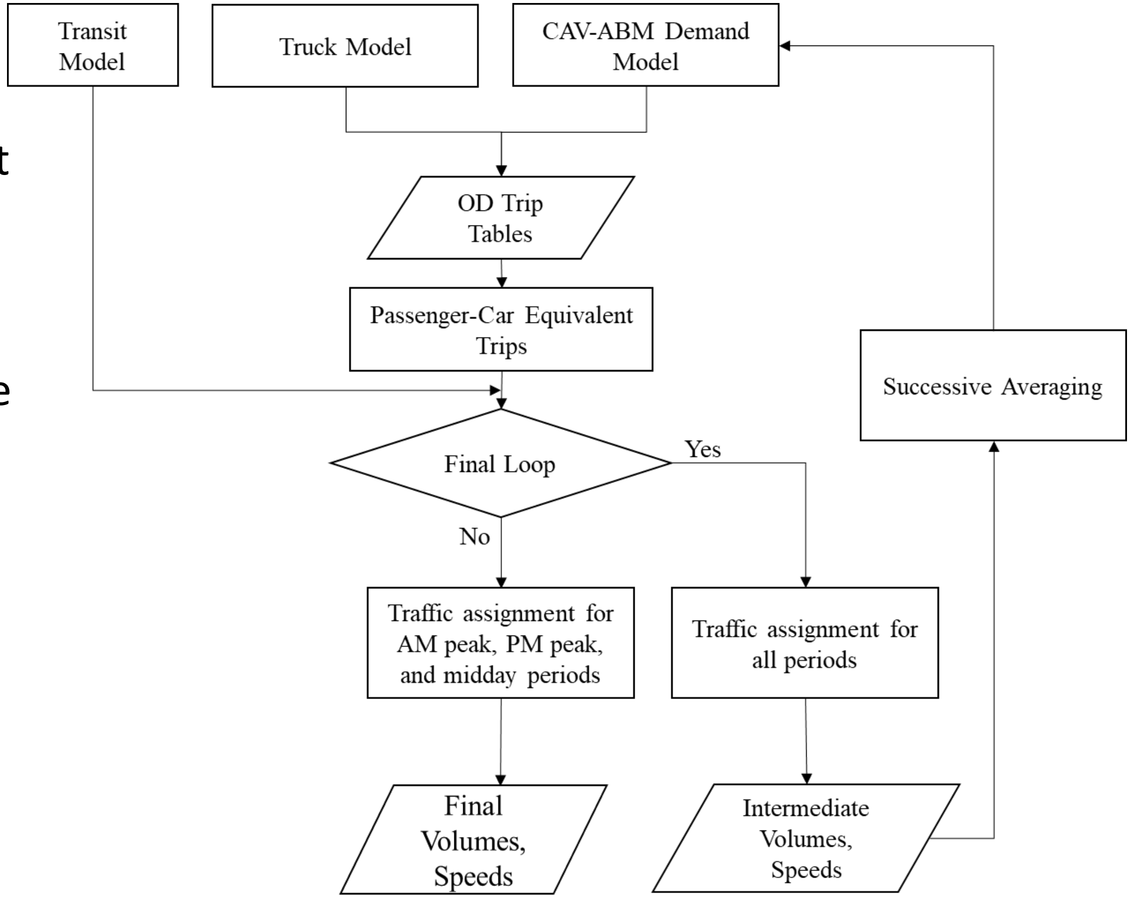
Methodology

Supply Side Model Update

- Increased roadway capacity by 15% according to Adebisi et al. (2020, 2022)
- Assignment process
  - Step 1: The initial demand are converted into OD tables and then loaded to the network to produce the first pass traffic volume and speed
  - Step 2: The congested speeds generated from the previous loop are further used as the inputs for the demand model in the following loop. The volume variation between assignment loops is smoothed by the method of successive averages.
  - Step 3: Loops before the final loop only produce assignments for AM and PM peaks, whereas the final loop perform assignments for all five time periods.



Model Assignment Framework

Methodology

Performance Metrics

- VMT
- Emission: The calculation is based on the emission factors proposed by EMFAC. Four major pollutants are selected:
    - CO2
    - NOx
    - PM2.5
    - Reactive Organic Gases (ROG)
- Transportation Equity:
    - Number of trips per household
    - Trip distance per household
    - Household travel accessibility
- The equity is evaluated across three income groups
    - Lower (annual income< $50,000)
    - Middle (annual income between $50,000 and $150,000)
    - Upper (annual income > $150,000)

$$Travel\ Accessibility = \frac{\sum_{j=1}^{n} \log \sum_{i=1}^{m_j} e^{u_{ij}}}{n}$$

$$u_{ij} = \sum_{k=1}^{K_j} v_{kij}$$

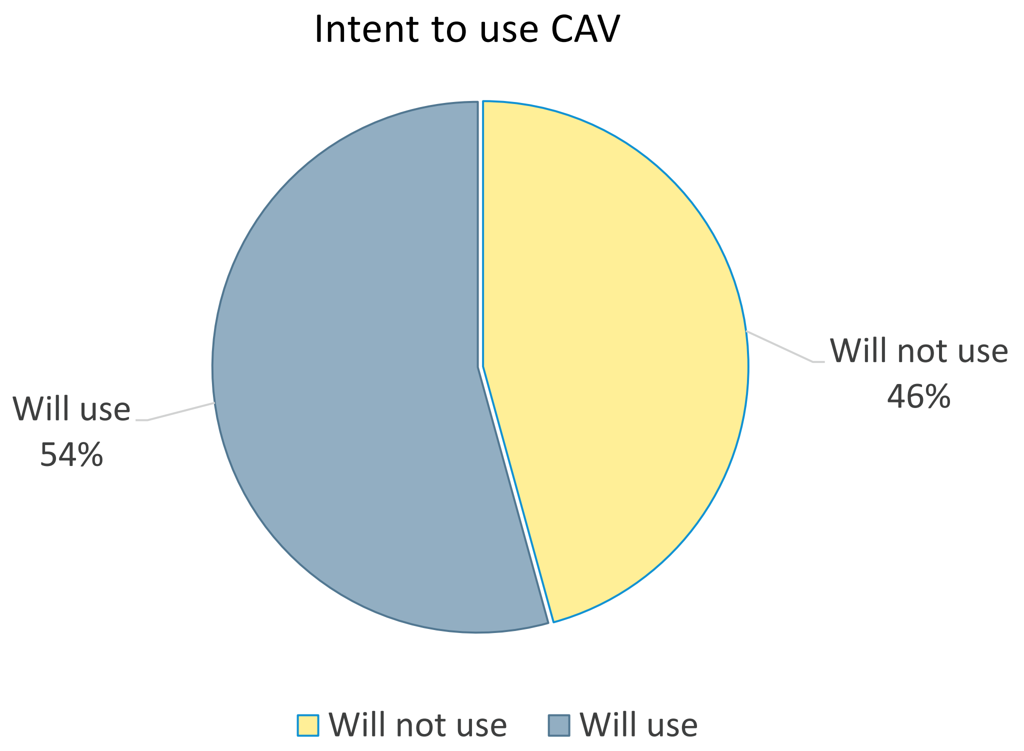
where,

- n is the number of tours of the household
- m_j is the number of available mode combinations of tour j
- u_{ij} refers to the sum of trip utilities of the ith available trip mode combination of tour j
- v_{kij} is the utility of the trip k in mode combination i of tour j
- K_j is the number of trips in tour j

Research Findings

Survey results

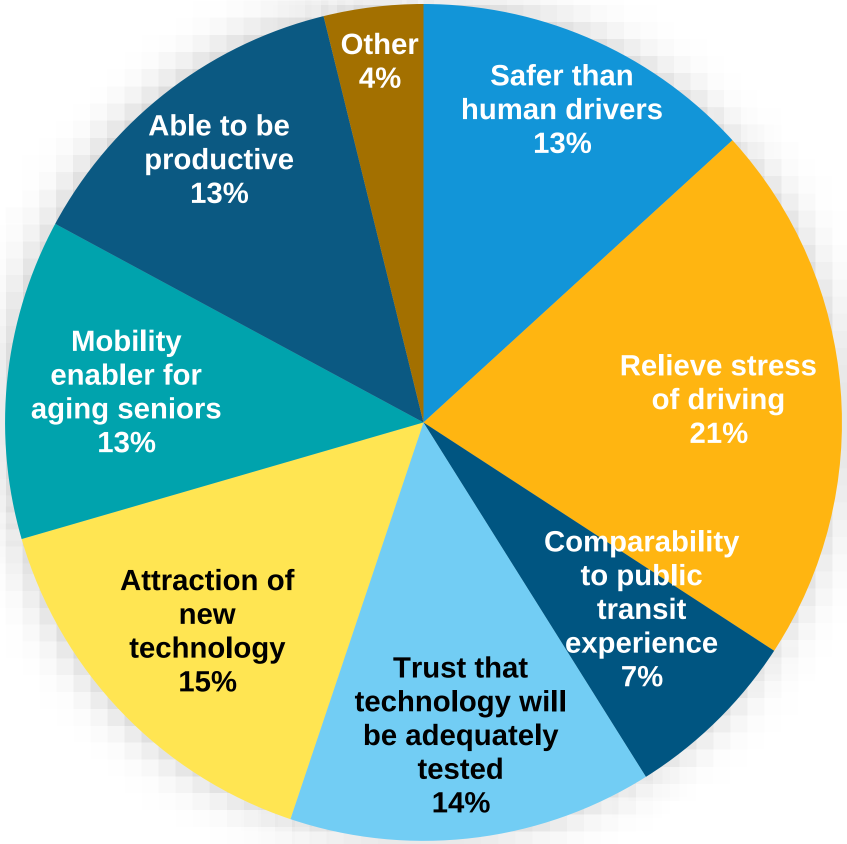
- At the first stage, about 54% of people choose to use CAV for their daily travel, which is close to the result (52%) of the 2017 California Vehicle Survey. The data collected from the second stage were used to re-calibrate/develop activity-related sub-models.



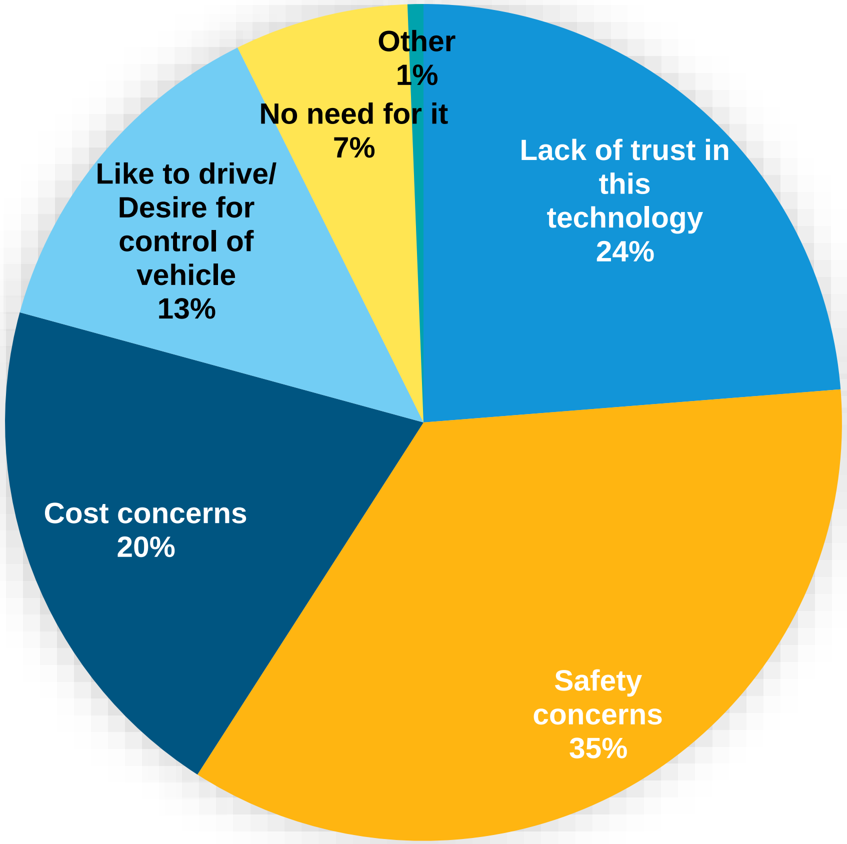
Research Findings

- Reasons why people choose to use CAV or not

Why use CAV



Why don't use CAV



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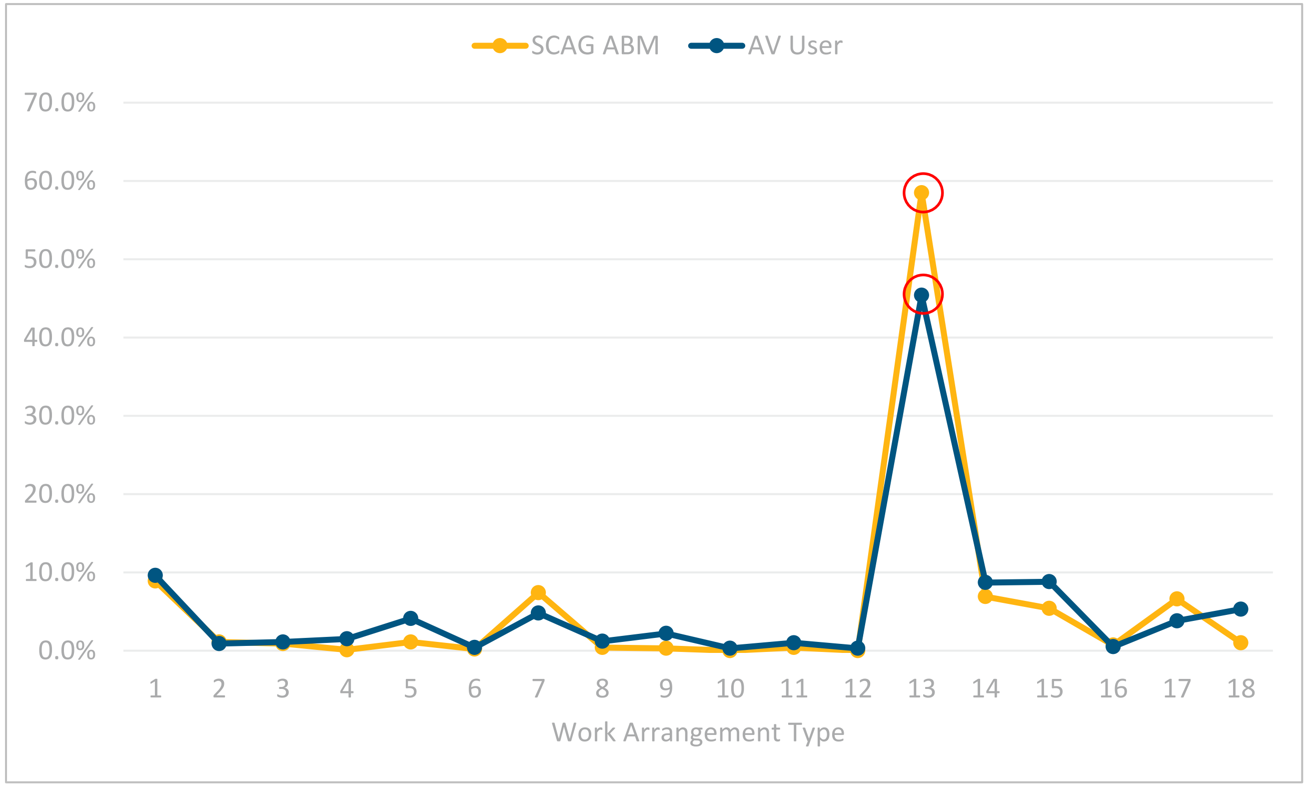
Research Findings

CHANGES IN WORK ARRANGEMENT

Distribution of work arrangement type



Lookup table of work arrangement type

ID	Work Duration	Workplace Type	Number of Jobs
1	Short	Fixed	One
2	Short	Fixed	Multiple
3	Short	Home	One
4	Short	Home	Multiple
5	Short	Variable	One
6	Short	Variable	Multiple
7	Medium	Fixed	One
8	Medium	Fixed	Multiple
9	Medium	Home	One
10	Medium	Home	Multiple
11	Medium	Variable	One
12	Medium	Variable	Multiple
13	Long	Fixed	One
14	Long	Fixed	Multiple
15	Long	Home	One
16	Long	Home	Multiple
17	Long	Variable	One
18	Long	Variable	Multiple

Research Findings

CHANGES IN WORK LOCATION CHOICE

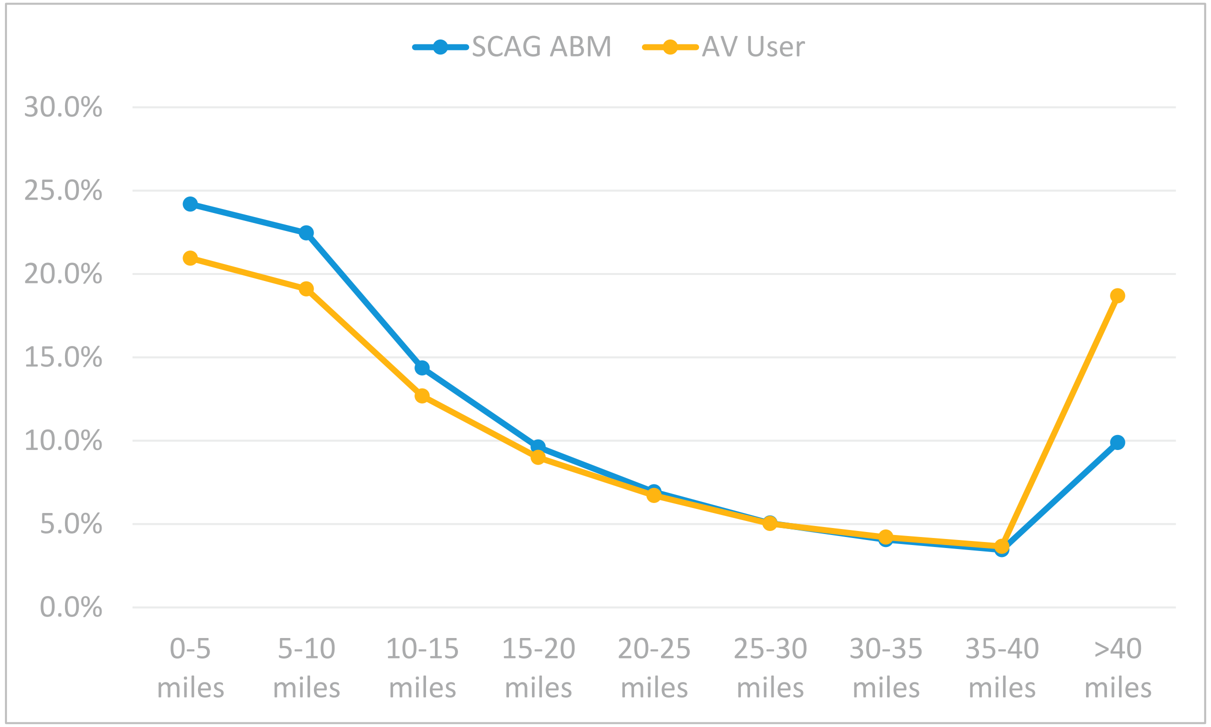
In SCAG model, the candidates of work location choice model are determined by a sample-by-importance approach. The utility of a candidate TAZ is:

$$V_{ij} = -\beta_1 * d_{ij} - \beta_2 * d_{ij}^2 + \ln(S_j)$$

where S_j is employment at the workplace TAZ. At most 30 TAZs can be selected for each worker.

In the CAV-incorporated model, we calibrated the β_1 and β_2 with the consideration of additional travel time accepted by CAV users.

Distribution of home-work location distance

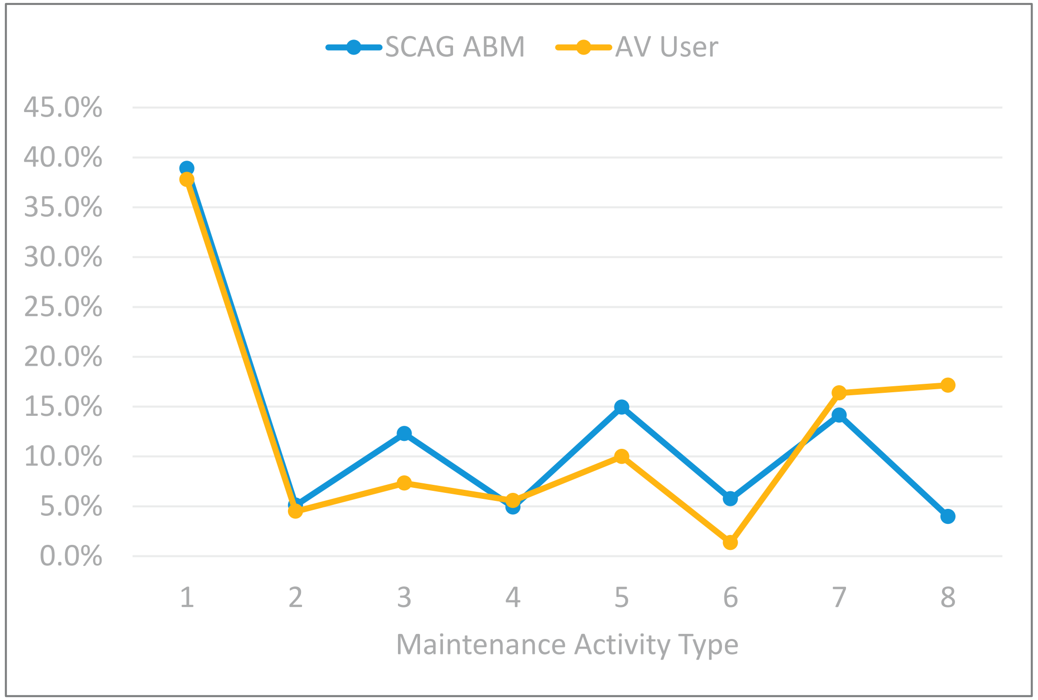


Average home-work distance changed from 18.3 miles to 22.1 miles.

Research Findings

CHANGES IN ACTIVITY FREQUENCY

Distribution of maintenance activity type



Non-mandatory activity is categorized as household maintenance activity and individual discretionary activity under the SCAG ABM framework.

Under the household maintenance activity, there are three sub-categories: grocery shopping ("S"), household errand (note as "M"), and escort ("E").

Lookup table of maintenance activity type

ID	Type	ID	Type
1	None	5	S
2	E	6	SE
3	M	7	SM
4	ME	8	SME

The number of household maintenance trips increased from 15.2M to 16.8M when CAV is available.

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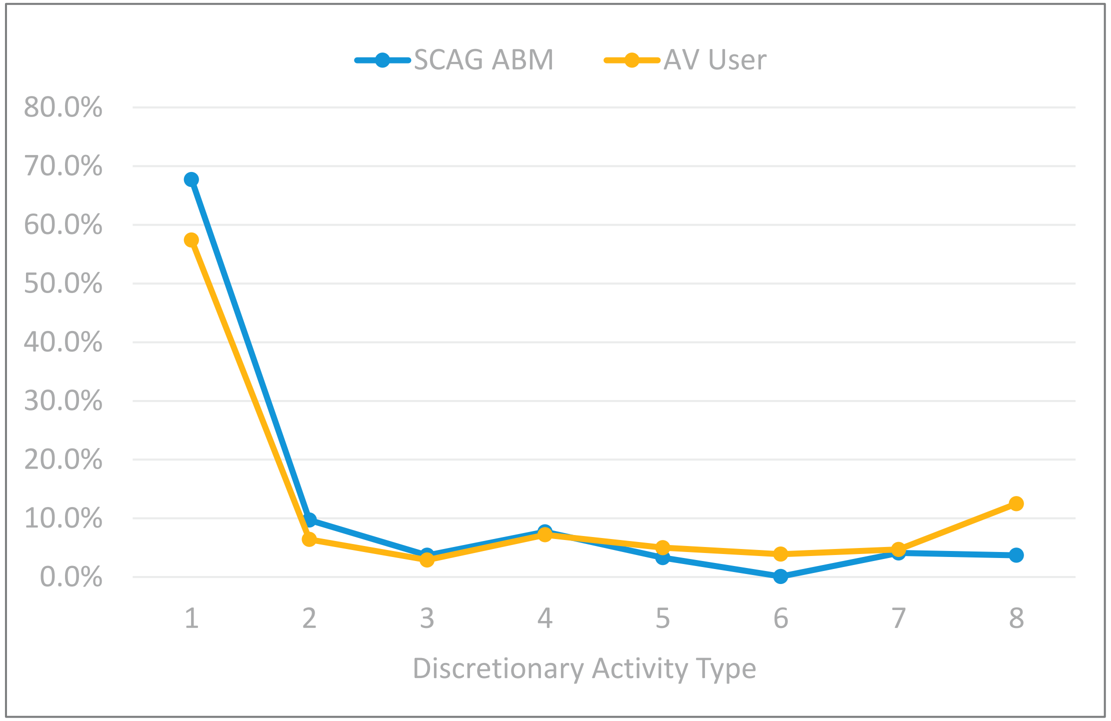
Research Findings

CHANGES IN ACTIVITY FREQUENCY

Distribution of discretionary activity type



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Under the individual discretionary activity, there are 3 sub-categories: visit ("V"), discretionary ("D"), and individual maintenance ("M").

Lookup table of discretionary activity type

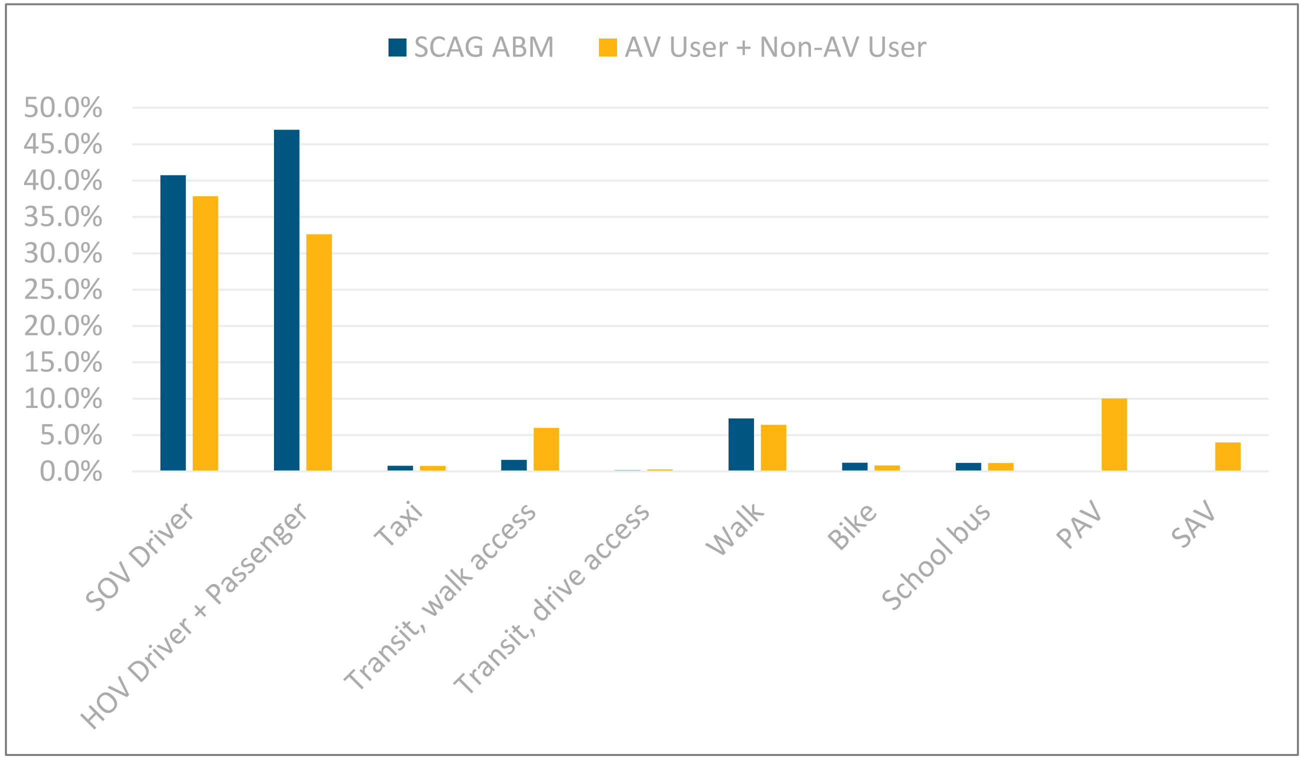
ID	Type	ID	Type
1	None	5	V
2	M	6	VM
3	D	7	VD
4	DM	8	VDM

The number of individual discretionary trips increased from 18.0M to 20.4M when CAV is available.

Research Findings

CHANGES IN MODE CHOICE

Comparison of Mode Choice



Research Findings

Demand-Side Impact

Changes in Number of Trips			
Trip Purpose	**SCAG**	**SCAG_CAV**	**Change in %**
Work	20,533,312	23,543,791	+15%
Household Maintenance	15,262,859	16,889,062	+11%
Discretionary	18,005,284	20,425,484	+13%

Research Findings

System Impact after 3 Feedback Loops

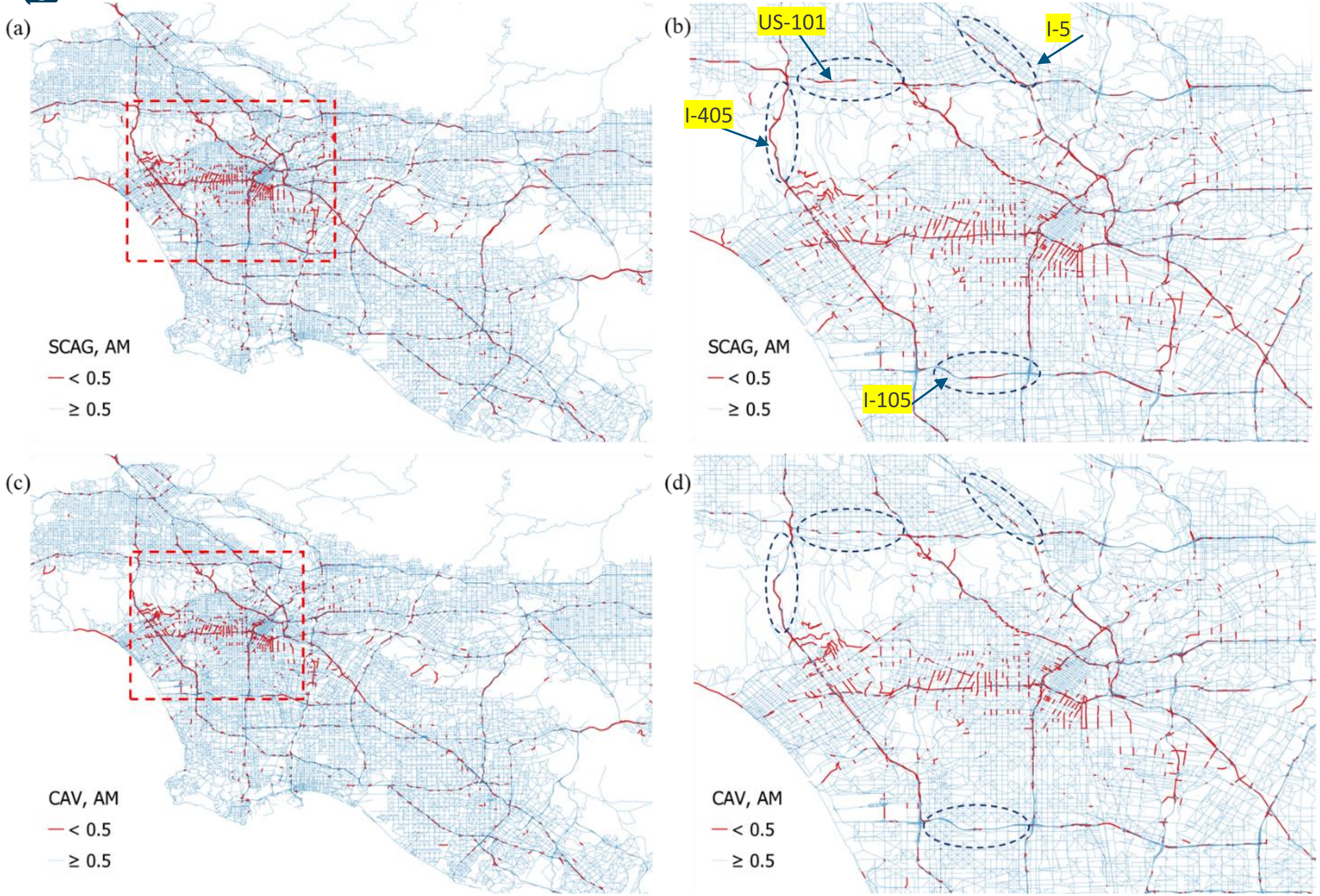
Metrics		SCAG	CAV Base	CAV Base (% change versus SCAG)
VMT	Total daily	4.57×10^8	4.99×10^8	9.1%
VHT	Total daily	1.39×10^7	1.44×10^7	3.6%
Total Daily Emission (ton)	NOx	26.57	29.22	9.6%
	PM2.5	0.67	0.74	10.4%
	CO2	1.39×10^5	1.53×10^5	10.1%
	ROG	6.61	7.25	9.7%

Research Findings

Spatial Distribution of AM Speed

- Congestion mainly on freeways and arterials near downtown LA
- The increase of speed is more significant on freeway links

Distribution of mean speed/free-flow speed during AM period



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Research Findings

Travel Demand Management Strategies Summarized by SCAG

- Parking
- Infrastructure & transit
- Incentive
- Marketing
- Other

Test Scenarios

- Scenario 1: Encouraging telework
  Scenario 2: Transit fare subsidy
- Scenario 3: Parking pricing
- Scenario 4: Auto trade-in

Metrics		SCAG	CAV Base	CAV S1 (Telework)	CAV S2 (Free Transit)	CAV S3 (Parking Pricing)	CAV S4 (Auto Trade-in)
VMT (mi)	Total daily (% change)	4.57×10^{8}	4.99×10^{8} (9.1%)	4.89×108 (6.9%)	4.95×108 (8.2%)	4.91×108 (7.5%)	4.68×108 (2.3%)
VHT (h)	Total daily (% change)	1.39×10^{7}	1.44×10^{7} (3.6%)	1.40×107 (0.7%)	1.42×107 (2.2%)	1.39×107 (0.0%)	1.29×107 (-7.2%)
Trips	Number of trips per household (% change)	12.8	13.67 (6.8%)	13.65 (6.6%)	13.67 (6.8%)	13.67 (6.8%)	13.23 (3.4%)
Mode Share	SOV	40.0%	38.0%	37.7%	37.7%	35.9%	33.7%
	HOV	48.0%	32.3%	32.5%	32.1%	33.7%	31.8%
	Transit	1.97%	6.32%	6.3%	7.0%	6.8%	7.2%
	CAV	NA	14.0%	14.1%	13.9%	14.2%	16.9%
	Other	10.1%	9.32%	9.4%	9.3%	9.4%	10.4%

Research Findings

Equity Analysis across Scenarios

- We used relative values instead of absolute values to represent the disparity across income groups for all of the three equity metrics.
- The outputs of the lower-income household are used as the baseline, whereas the outputs of the middle- and upper-income households are represented in relative values proportional to the baseline.

Equity Index

- We defined an equity index (EI) to represent the disparity across income groups. The lower the EI, the better the equity. SCAG's EI is set to be 1. Negative EI means lower income groups outperform middle- and upper- income groups.

Number of Trips per Household

Model	Mandatory Activities		
	Lower	Middle	Upper
SCAG	3.56	5.09	5.37
CAV Base	3.75	5.24	5.51
CAV Scen 1	3.73	5.19	5.40
CAV Scen 2	3.75	5.24	5.51
CAV Scen 3	3.75	5.24	5.51
CAV Scen 4	3.55	5.06	5.30
CAV Scen 3 *	3.75	5.24	5.52
CAV Scen 4 *	3.75	5.12	5.31

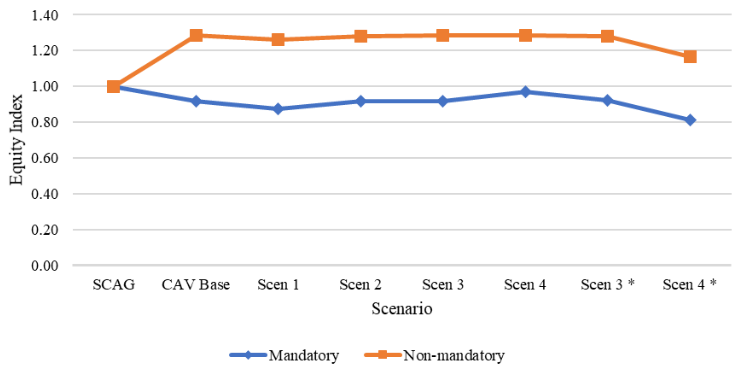
Relative Number of Trips per Household

Model	Mandatory Activities			
	Lower	Middle	Upper	Equity Index
SCAG	1.00	1.43	1.51	1.00
CAV Base	1.00	1.40	1.47	0.92
CAV Scen 1	1.00	1.39	1.45	0.87
CAV Scen 2	1.00	1.40	1.47	0.92
CAV Scen 3	1.00	1.40	1.47	0.92
CAV Scen 4	1.00	1.43	1.49	0.97
CAV Scen 3 *	1.00	1.40	1.47	0.92
CAV Scen 4 *	1.00	1.36	1.41	0.81

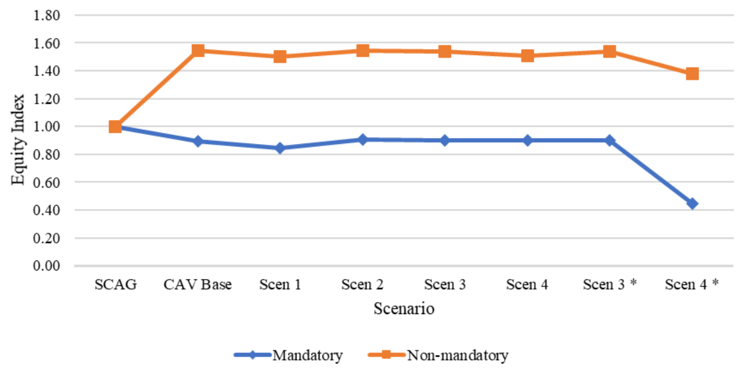
* means adjusted strategies by modifying the policy more in favor of the lower-incomes.

Research Findings

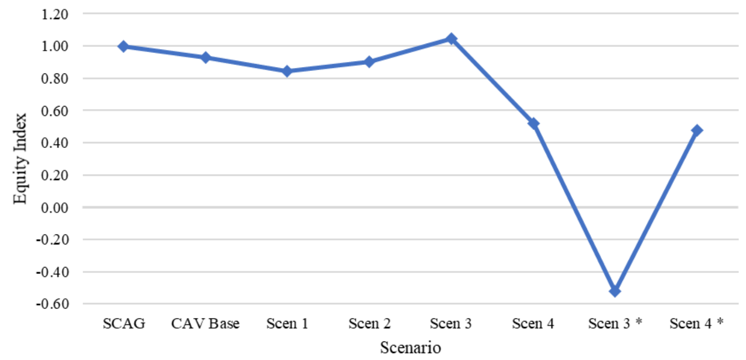
- Compared with SCAG model, CAV models indicate improved equity on mandatory trips , whereas decreased equity on non-mandatory trips.
- By adjusting the policy more in favor of the lower-income groups, the equity performance increases significantly compared with the generic policy scenarios.
- Too much support on lower-income households might also cause inequity across income groups. (Scenario 3 *)



(a) Equity Index on Number of Trips per Household



(b) Equity Index on Travel Distance per Household



(c) Equity Index across Scenarios on Travel Accessibility

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Policy Recommendations

- Pricing policies
  - Parking pricing: charge more for SOVs and PAVs, while less for HOVs and SAVs
- Infrastructure improvement
  - Transit incentives have little improvement. Consider upgrading the level of service of the transit system
- Encouraging to work remotely
- Marketing strategies for CAV ownership:
  - Encourage and subsidize households to trade-in old regular vehicles for CAVs

Conclusion

- According our survey, a little more than half (54%) of the population is willing to adopt CAV for travel
- When CAV is available, people's travel behaviors changed significantly:
    - More flexible work arrangement is preferred
    - Longer home-work distance is accepted
    - More business/non-mandatory trips are expected
- Number of trips (11% to 15%), VMT (9.1%) and emissions (9% to10%) are significantly increased due to the CAV deployment
- The reduction on congestion is limited, only speed on freeway during AM has a slight increase (5.4%).
- Auto trade-in policy is the most effective in reducing the VMT and emission growth among others.
- After deploying CAVs, the disparity across different income groups decreases with respect to mandatory activities. On the other hand, the disparity increases for non-mandatory activities.
- By introducing income-specified TDM strategies, the policies become more effective in enhancing the equity.

Conclusion

More details of this study can be found in:

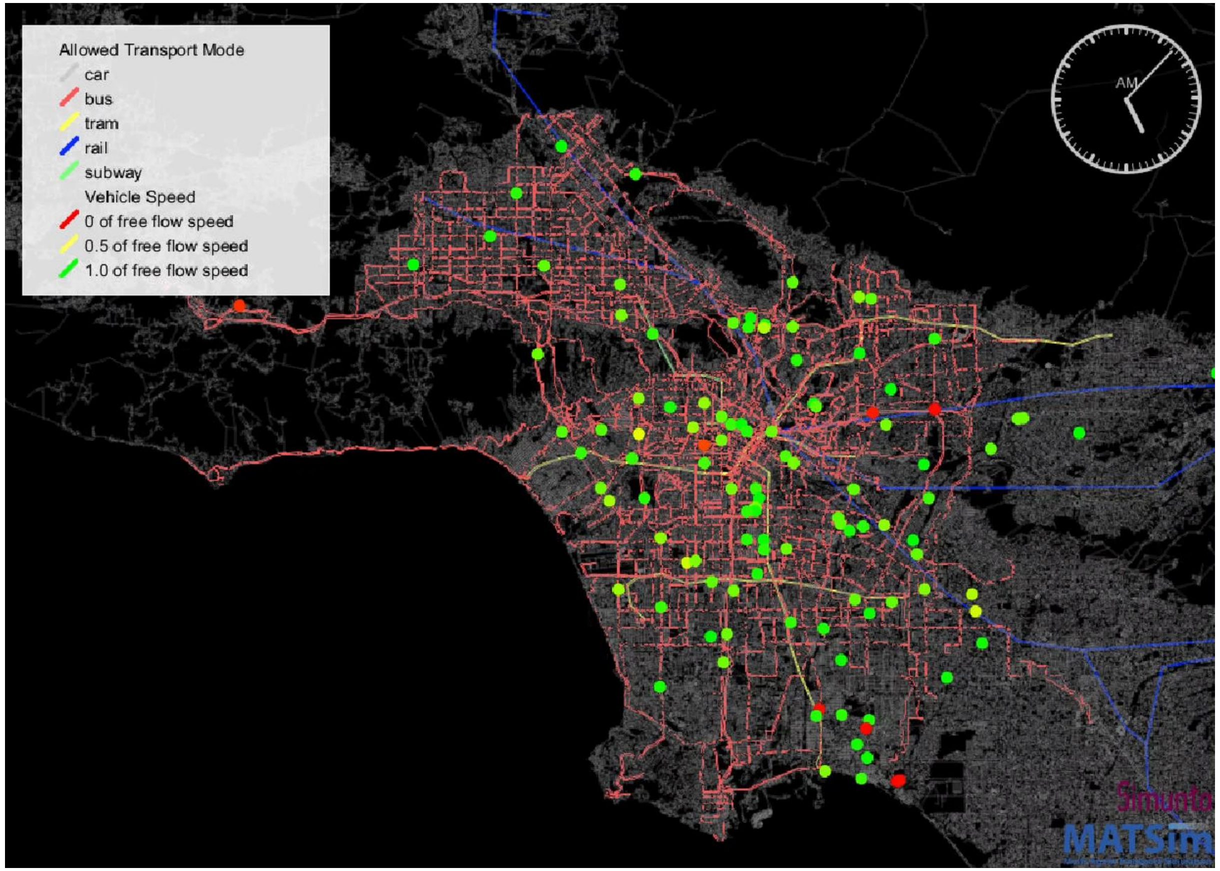
- Yueshuai He, B., Jiang, Q., & Ma, J. (2022). Connected automated vehicle impacts in Southern California part-I: Travel behavior and demand analysis. *Transportation Research Part D: Transport and Environment*, *109*, 103329. https://doi.org/10.1016/j.trd.2022.103329
- Jiang, Q., Yueshuai He, B., & Ma, J. (2022). Connected automated vehicle impacts in Southern California part-II: VMT, emissions, and equity. *Transportation Research Part D: Transport and Environment*, *109*, 103381. https://doi.org/10.1016/j.trd.2022.103381

Dynamic Traffic Assignment

- Based on the travel demand prediction from the SCAG ABM, we developed a dynamic traffic assignment model with the open-source toolkit -- Multi-Agent Transport Simulation (MATSim)

- The MATSim simulates passenger travel behaviors and vehicle movements in a multi-modal network, which captures the dynamic interactions between passengers/vehicles and the network.

- Agents can change multiple travel behaviors during the simulation
  - Mode choice
  - Route choice
  - Departure time choice



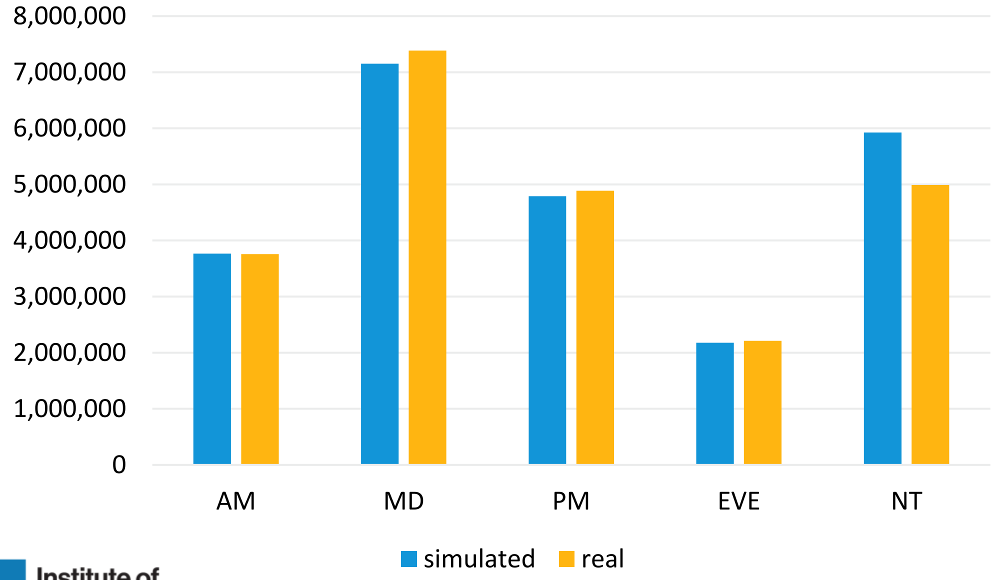
Dynamic Traffic Assignment

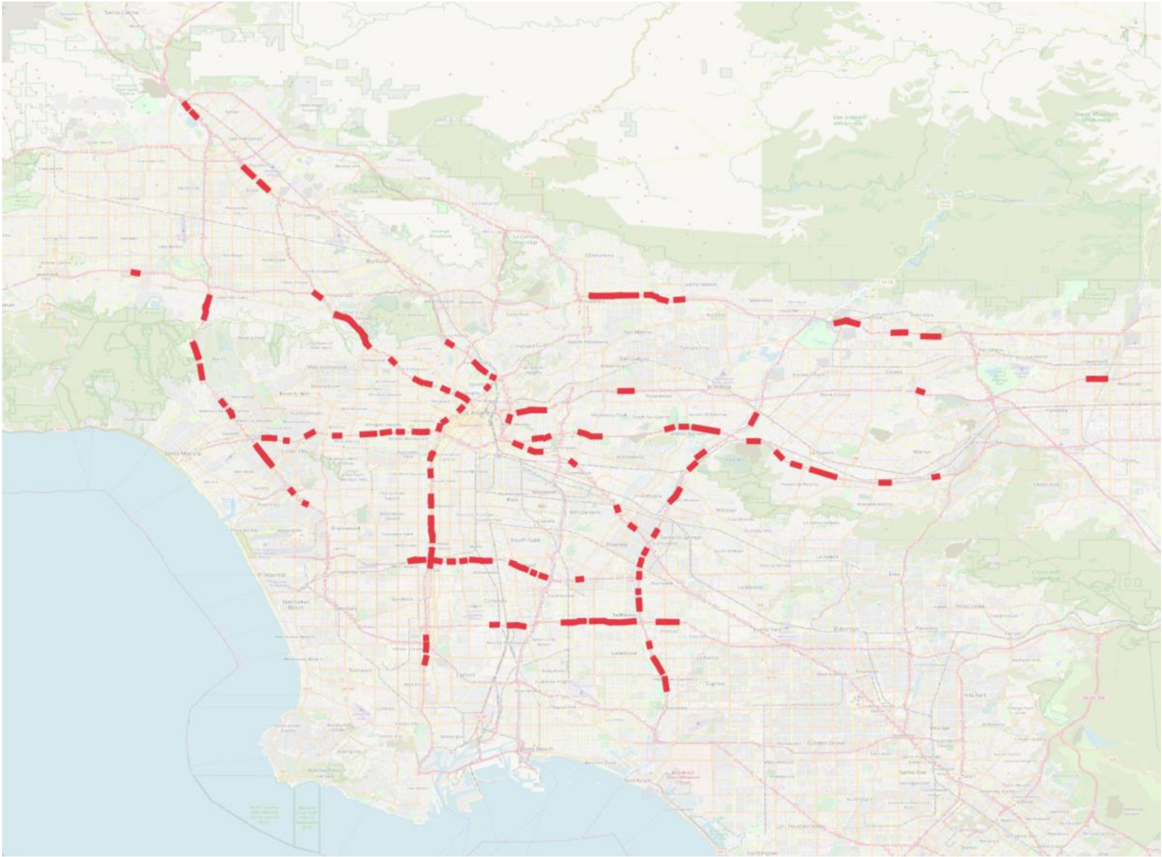
- Basic input
  - Synthetic population
  - Multimodal network
    - Road network from OpenStreetMap
    - Transit network and schedules/timetables from GTFS
  - Activity-based travel demand (SCAG ABM)

- Typical output
  - Individual level travel trajectories
  - Link level traffic volumes and travel times
  - Community level emission estimation from the transportation sectors

Dynamic Traffic Assignment

- Calibration and validation
  - 10% of population in the LA County was simulated
  - The link capacity of freeways was calibrated in five time periods
  - The simulated volumes were validated to traffic count data from locations of major freeways





Traffic count locations selected in LA County

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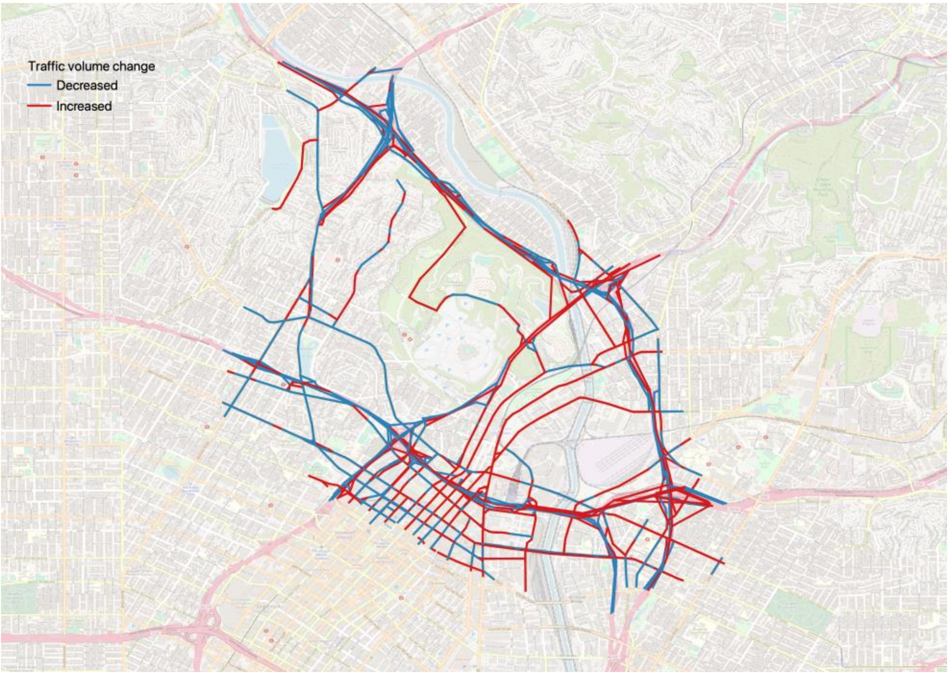
Dynamic Traffic Assignment

- Versatile Applications
  - Congestion pricing analysis (Downtown LA)
  - Proposed transit service evaluation (Los Angeles Aerial Rapid Transit, LAART)
  - Electric vehicle charging demand prediction
  - New mobility simulation (CAV, shared mobility, micro-mobility)
  - Mobility hub
  - Environment and public health benefits of zero-emission vehicles



Changes in traffic volumes around the Dodger Stadium before and after the implementation of LAART

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Thank You

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