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Evaluate the System-Level Impact of Connected and Automated Vehicles Coupled with Shared Mobility: An Agent-based Simulation Approach

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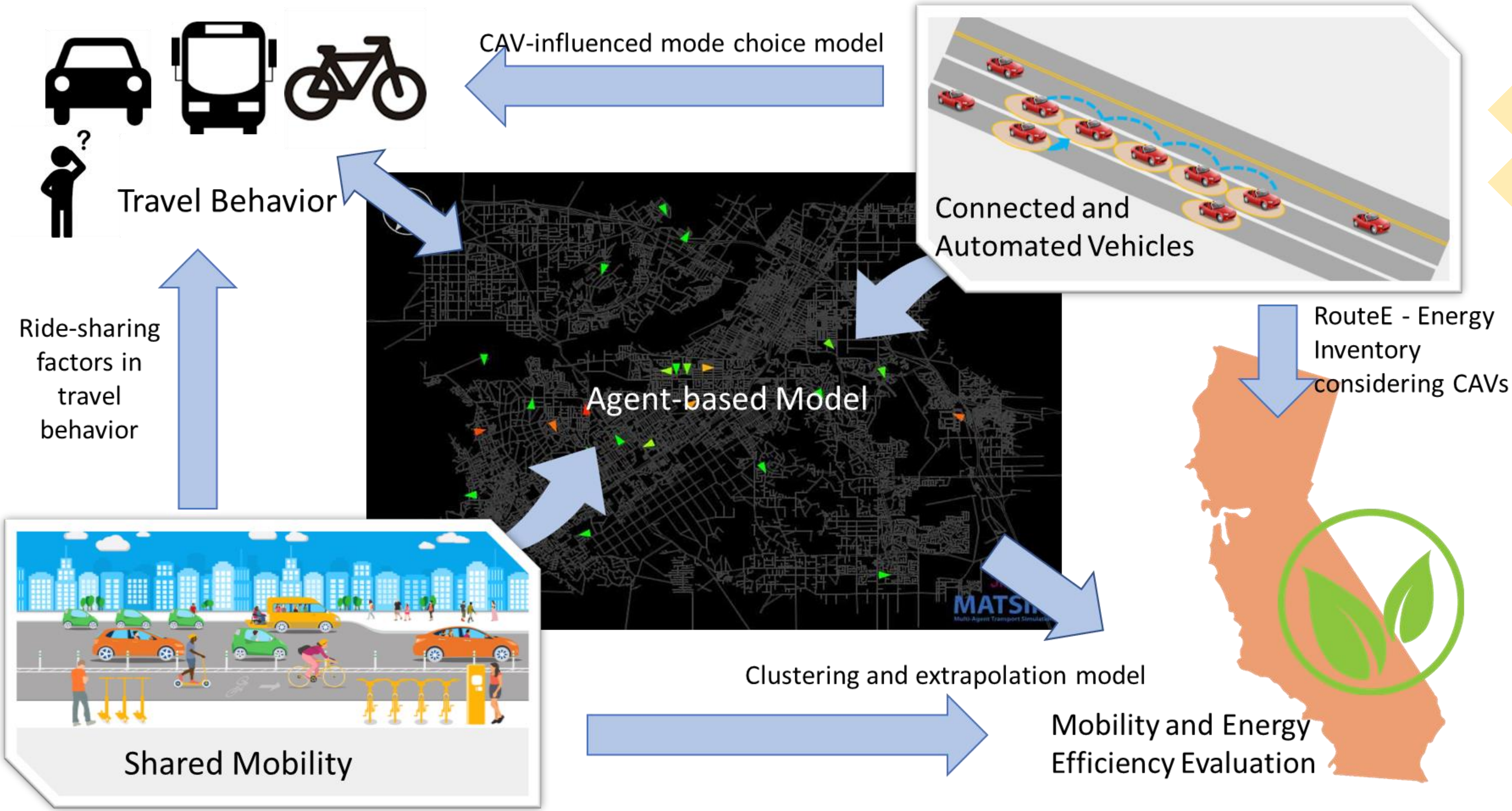
Background

- Connected and Automated Vehicles (CAVs) are deemed to be disruptive with the potential to significantly improve overall transportation system efficiency, however, may bring Vehicle Miles Traveled (VMT) increase or other issues.
  - By taking advantage of vehicle-to-vehicle (V2V) communications, CACC allows vehicles to form platoons and travel at harmonized speeds with shorter time headways between them.
  - Some pilot applications, such as EAD and eco-speed harmonization, have been developed and deployed based on V2V and vehicle-to-infrastructure (V2I) communications, showing significant savings on fuel consumption
- Shared mobility systems are another disruptive force that is reshaping our travel patterns
- Studies have shown that shared mobility can reduce the vehicle ownership, usage, and vehicle miles traveled (VMT), and therefore benefit entire transportation system
- There is a knowledge gap on recognizing the potential energy impacts of a broad deployment of CAV technologies and shared mobility services.

Objectives

- To quantify the combined impact of CAV and shared mobility on travel behavior, traffic performance and energy efficiency, we develop a mesoscopic simulation-based framework for mobility and energy efficiency evaluation considering the disruptive transportation technologies.
- Under this framework, we develop novel models for energy intensity and modal activity, and evaluated a variety of energy scenarios for different combinations of CAV applications, various levels of automation, roadway characteristics, and traffic conditions, while also varying different vehicle types and fuel/powertrain technologies.
- An agent-based simulation model is then developed in BEAM to integrate all the components in a network of the City of Riverside. Impact analysis on mobility, vehicle-miles-traveled (VMT) and energy are conducted based on the simulation results from multiple scenarios.

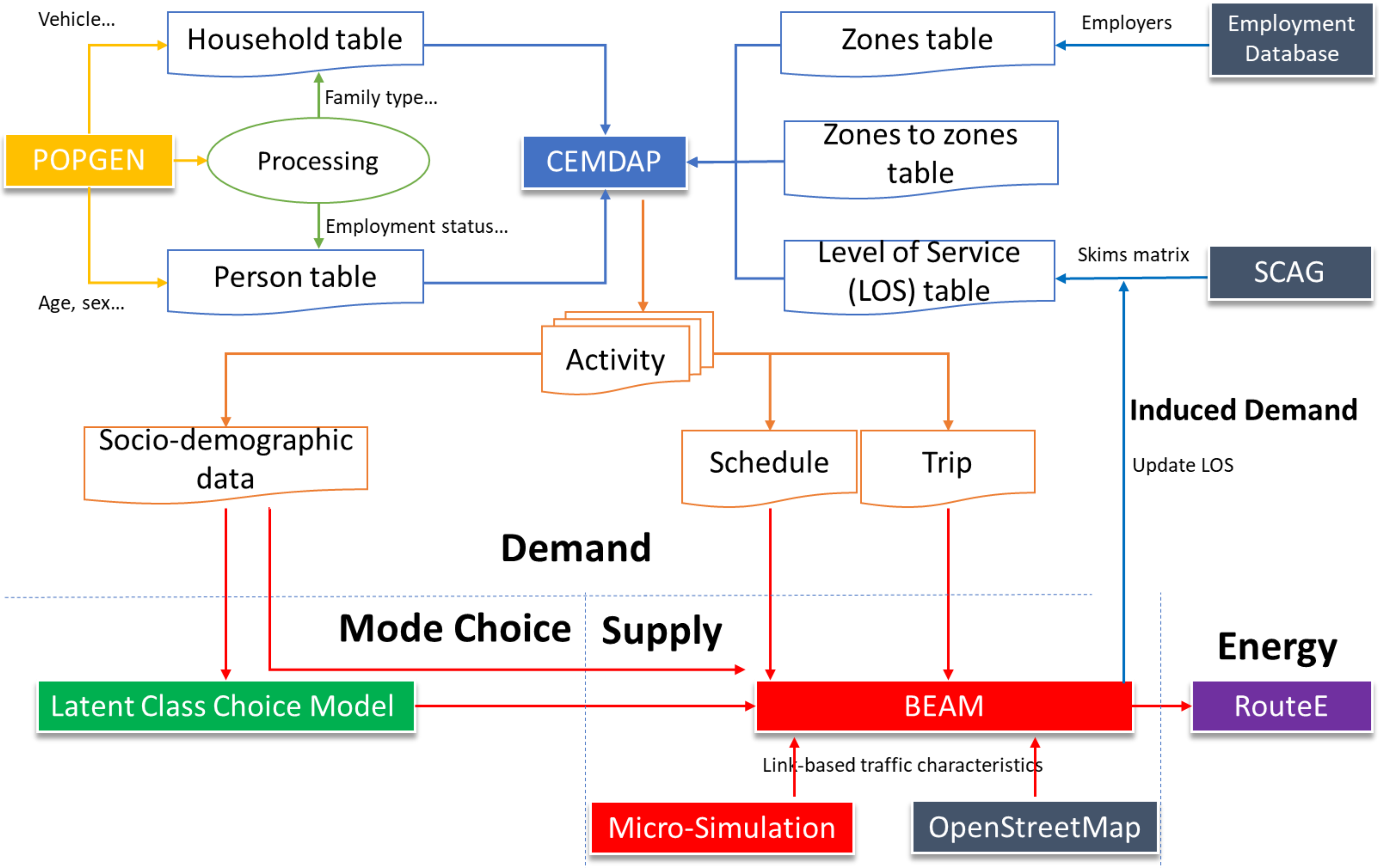
Model Framework



Key Components

- **Energy Intensity Model**: RouteE model developed by NREL is upgraded to integrate CAV-related factors for energy evaluation in the BEAM platform. Microsimulation results from CAVs technologies such as CACC and EAD were collected and processed to quantify their impacts on energy consumption and VMT under different penetration rates.
- **Mode Choice Model**: a novel fundamental influencing factor (FIF) mode choice model is developed, linking CAV and shared mobility components with travel behavior. The introduction of new transportation technologies is expected to greatly affect daily travel behavior and consequently influence the mobility and energy performance of the transportation system.
- **Riverside BEAM Model** and **Impact Evaluation Model** are developed to link the BEAM simulation with mobility, VMT and energy efficiency results, considering the impact of CAVs and shared mobility. BEAM is selected as the main simulation platform due to its support of shared mobility modeling, its ability to deal with large-scale networks, and its synergistic nature with other ongoing work in California.

System Diagram for BEAM-centered Approach



Model Implementation

- To provide high resolution activity input data for BEAM, Popgen was applied to generate socio-economic characteristics for each person and for each household in the area.
- The Southern California Association of Governments (SCAG) travel demand model was used to estimate the transportation system level of service for each origin-destination pair.
- CEMDAP model was employed to simulate daily activities and travel patterns of all individuals.
- The modified fundamental influencing factor (FIF) mode choice model was integrated into BEAM to enable refined and defensible estimation of travelers' mode choice preferences in the study area when faced with hypothetical future CAVs and shared mobility scenarios.
- We utilized BEAM's internal engine to model ridership under Transportation Network Company (TNC) and shared autonomous vehicles (SAVs).
- RouteE model receives the link-by-link activity output from BEAM to estimate the energy use for a certain vehicle route, which is further utilized to estimate the energy consumption in any scale.

BEAM Simulation

City of Riverside BEAM simulation visualized by Via

(Video attached in a separate file)

Scenario Design

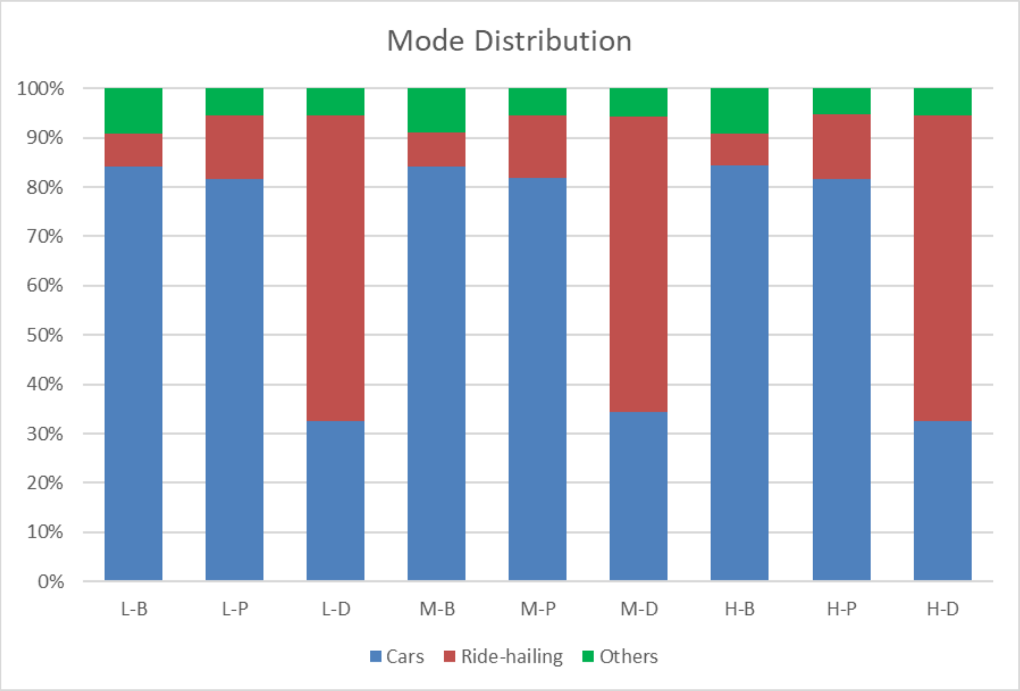
- Based on the well-calibrated Riverside BEAM model, we design scenarios to study the joint impact of CAVs and shared mobility. The impact of the CAV technology includes:
  - 1. Mobility enhancement, e.g. link capacity increase which will be shown later
  - 2. Energy economy improvement according to RouteE model
  - 3. Better use of in-vehicle time and then mode choice shifts according to FIF mode choice model
- The impact of CAV-related operation model includes:
  - 4. Lower price for SAV fleet by cutting driver cost
  - 5. Overusing issue for private AVs if there is no regulation
- The CAV technology penetration rate has three levels, low (L), medium (M) and high (H).
- The operation model of shared fleet has three levels: baseline (B), popular (P) and dominant (D).
- We then design 9 different future scenarios in terms of penetration rate of CAV technology and operation model of shared (AV) fleet to cover all possible combinations.

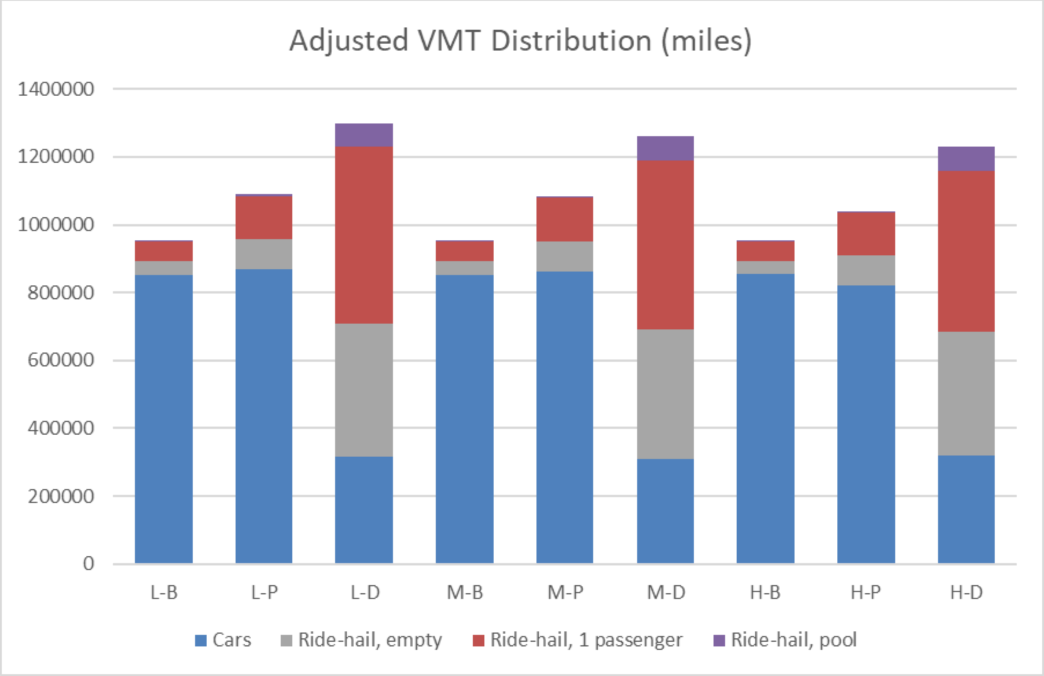
Scenario Design

- **L-B scenario**: low level on CAVs, baseline level on sharing. This is the baseline scenario corresponds to the current CAV and ride-hailing situation in the City of Riverside.
- **L-P scenario**: low level on CAVs, popular level on sharing. In this scenario, we assume shared mobility gains more acceptance and popularity, but the CAV penetration is still under low level.
- **L-D scenario**: low level on CAVs, dominant level on sharing. In this scenario, we assume the automation level of CAV evolves high enough to operation SAV fleets, but SAVs are not well coordinated due to the failure in developing or promoting connectivity technology.
- **M-B scenario**: medium level on CAVs, baseline level on sharing. In this scenario, we assume 40% of vehicles are upgraded to CAVs, but the shared mobility model stays at the baseline level.
- **M-P scenario**: medium level on CAVs, popular level on sharing. In this scenario, we assume 40% of vehicles are upgraded to CAVs, and shared mobility gains more acceptance and popularity at the same time.
- **M-D scenario**: medium level on CAVs, dominant level on sharing. In this scenario, we assume the automation level of CAV becomes high enough to operation SAV fleets, and 40% of entire vehicles are upgraded to CAVs.
- **H-B scenario**: high level on CAVs, baseline level on sharing. In this scenario, we assume 80% of vehicles are upgraded to CAVs, but the shared mobility model stays at the baseline level.
- **H-P scenario**: medium level on CAVs, popular level on sharing. In this scenario, we assume 80% of vehicles are upgraded to CAVs, and shared mobility gains more acceptance and popularity at the same time.
- **H-D scenario**: medium level on CAVs, dominant level on sharing. In this scenario, we assume the automation level of CAV becomes high enough to operation SAV fleets, and 80% of entire vehicles are upgraded to CAVs with good coordination. This is the ultimate scenario with optimistic hypothesis on CAV technology and shared mobility business models.

Impact Evaluation on Travel Behavior

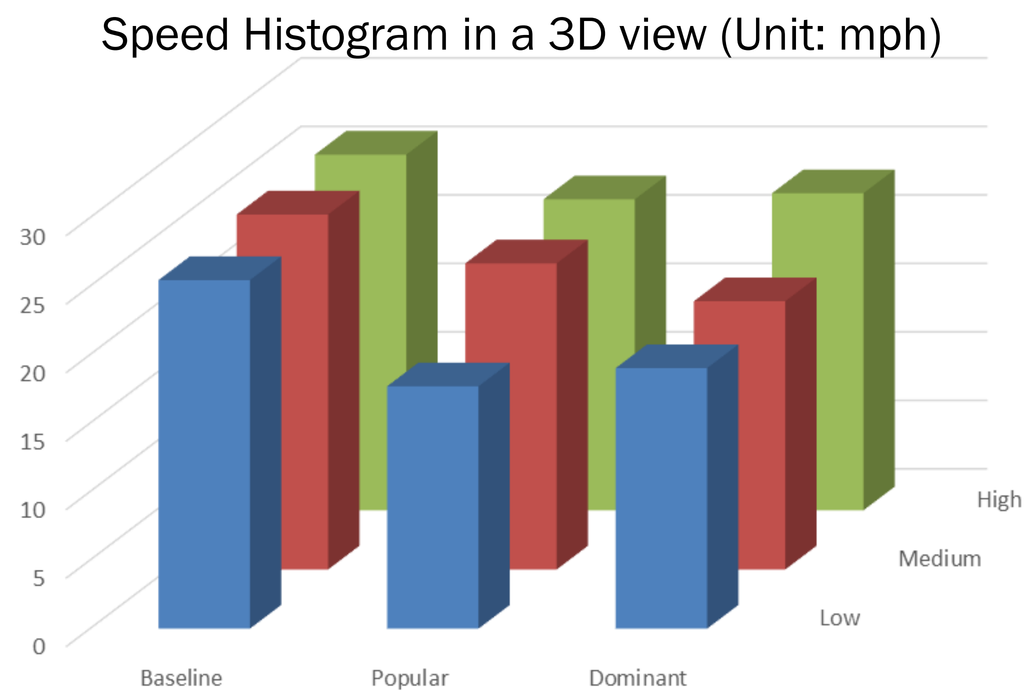
- Over half of the non-motorized travelers switch his/her mode during this expansion of ride-hailing. over half of the private car drivers switches to ride-hailing in the SAV era.
- There is significant increasing trend in VMT by raising the popularity of ride-hailing





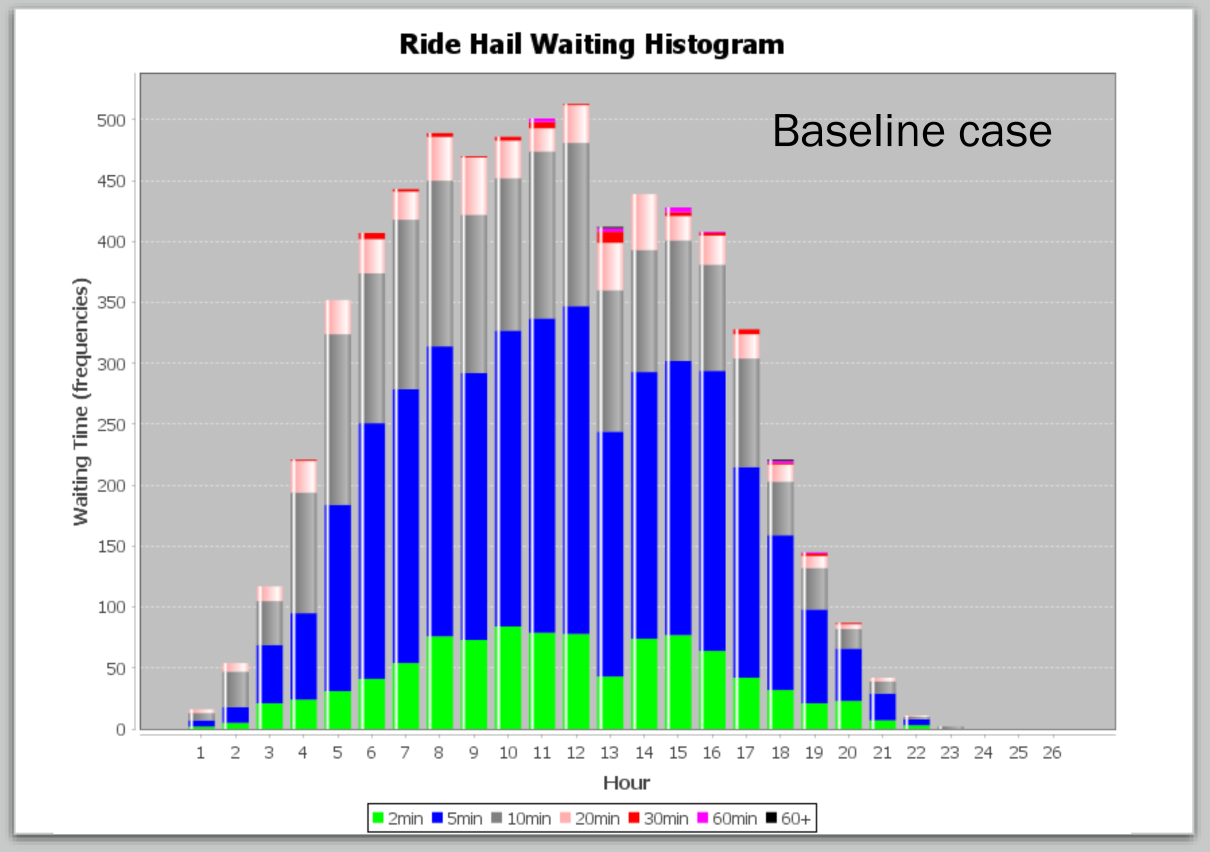
Impact Evaluation on Mobility

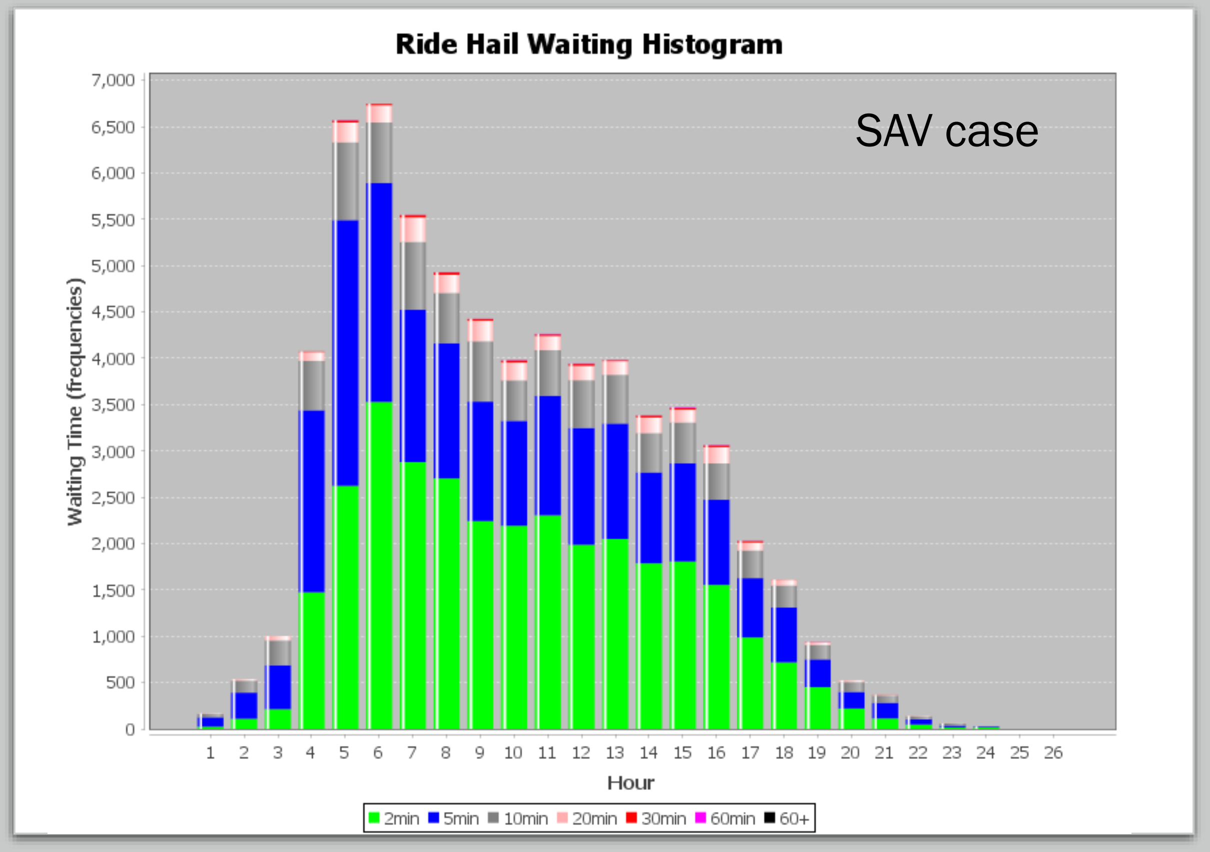
- When increasing the CAV penetration rate from 0 to 80%, the average speed of baseline, popular and dominant level scenario increases by 2%, 28% and 21%, respectively.
- On the other hand, ride-hailing and ridesharing would cause additional delay when fixing CAV penetration



Impact Evaluation on Waiting Time

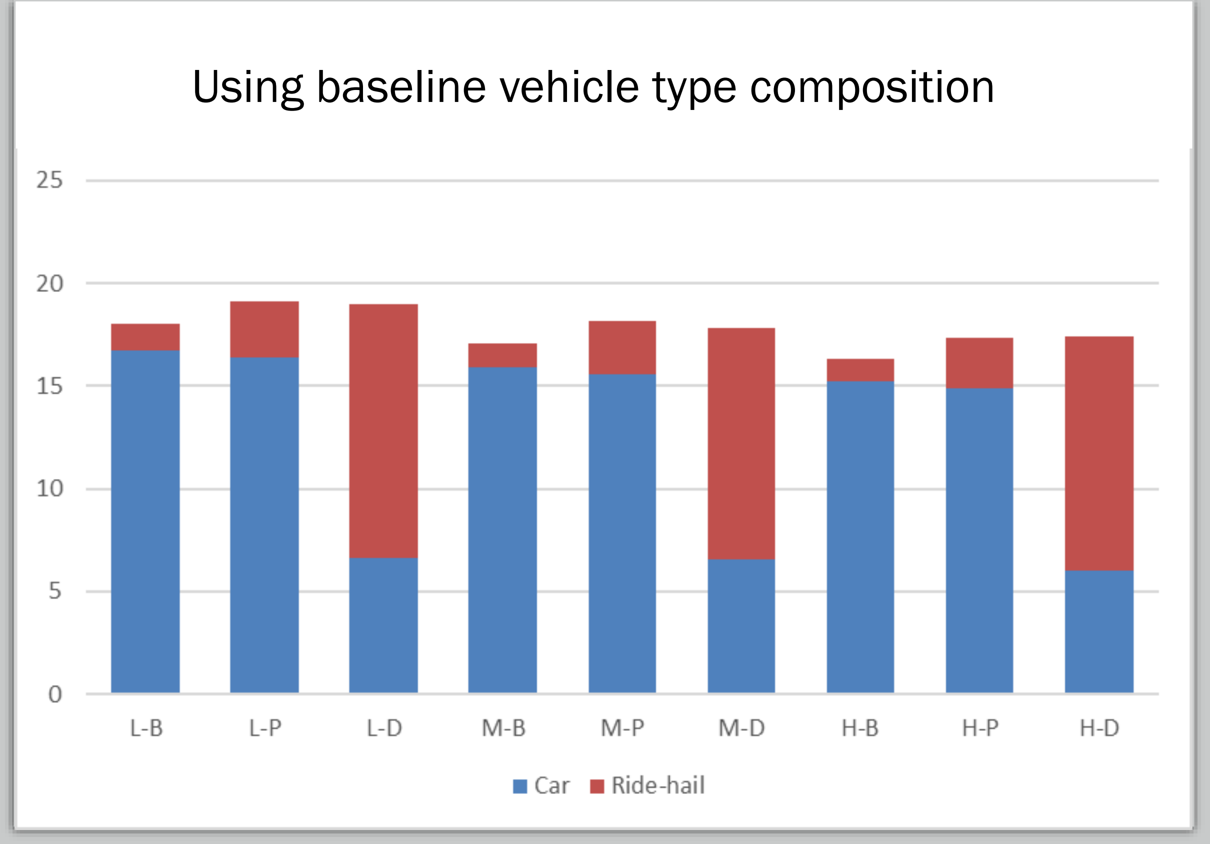
- The average waiting time is 298s for baseline ride-hailing scenarios, and 226s for both popular and dominant scenarios.
- Ride-hailing vehicles mainly serve for non-commute trips, but SAVs will be as competitive as private car in commute trips

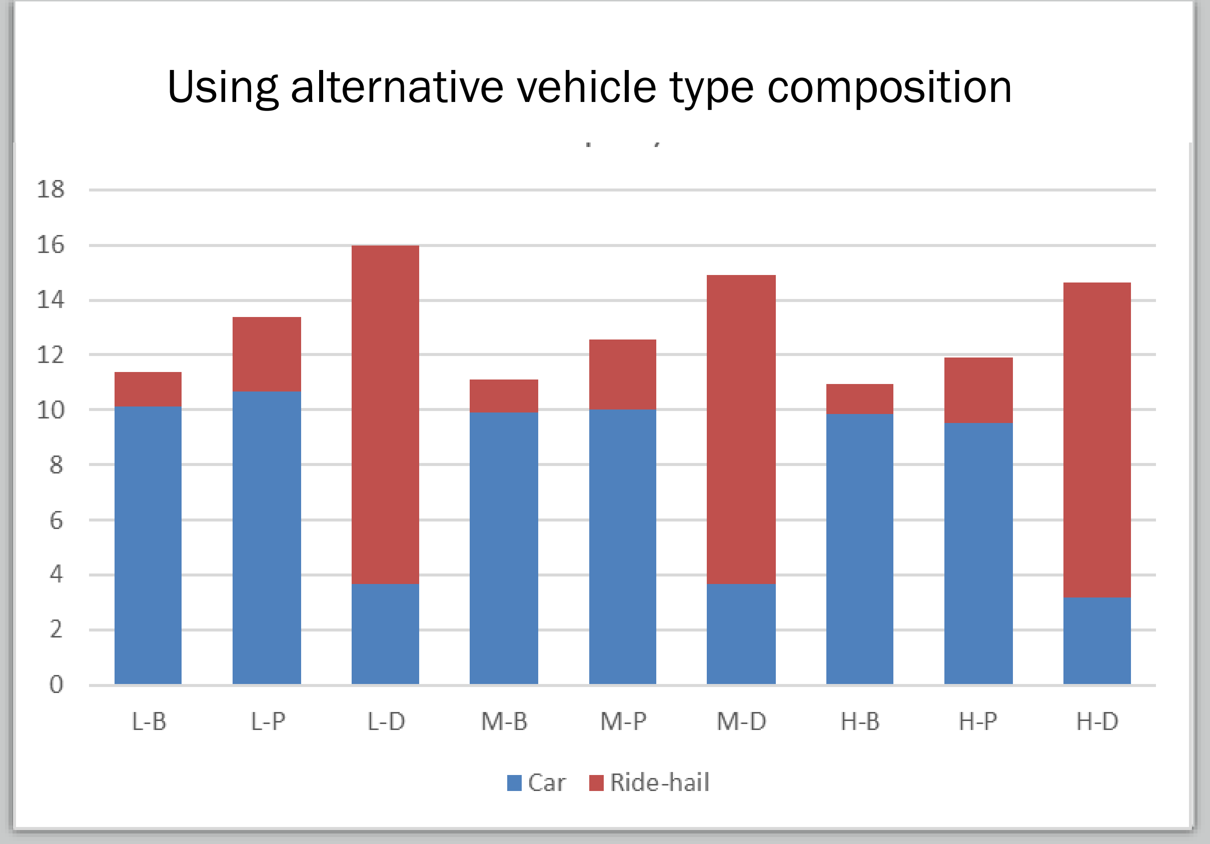




Impact Evaluation on Energy

- If assuming higher EV/HEV rate for ride hailing vehicles, ride-hailing slightly increase energy consumption and CAV slightly reduce energy consumption .
- If assuming same EV/HEV rate for both private and ride hailing vehicles, SAV would increase the energy consumption by 40%.





Conclusions

- We develop a mesoscopic simulation-based framework to quantifying the combined impact of CAV and shared mobility.
- We built Riverside model, the first BEAM model in Southern California, to implement applications that are associated with CAV and shared mobility.
- By applying this modeling suite to a calibrated network in Riverside California, it was found that cooperative automated driving in general will improve mobility, but automated vehicles, even when deployed in a shared autonomous fleet, will likely bring an increase of VMT (up to 36%) due to mode shifts and deadheading.
- Ride-hailing vehicles typically have better energy efficiency and a higher share of electric vehicles, which helps offset the negative impact from VMT increases when estimating the system-level energy consumption.
- In general, simulation results show a 6% increase in energy consumption for the scenarios with an increasing shift to ride-hailing modes.

- Thank you
- Questions or Comments ?

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