![NREL Transforming ENERGY]

Modeling Transitions to Connected and Automated Vehicles

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OVERVIEW

Timeline: March 2017 – June 2019
Total Funding: $315,000

RELEVANCE

Objectives

Determine how cost, technology, and stakeholder behavior can accelerate or impede CAV adoption and affect energy use, both during transition and at end states with varying CAV use, through development of a semi-quantitative "CAV scenario generation" model, identifying data gaps needing future research.

Impact

Supports efforts to estimate potential energy and mobility impacts of CAVs at both a national level and in 50+ metropolitan regions by creating a nimble analytic tool that stakeholders can use to generate numerous scenarios for CAV adoption under a variety of conditions to understand the range of effects of CAVs and the circumstances likely to lead to particular CAV outcomes.

SUMMARY

- Developed the CAV scenario generation model and performed analysis of CAV adoption and energy outcomes under numerous scenarios of costs, technology development, and behavior.
- Evaluated known and hypothetical situations with possibly adverse effects.
- Ranked and quantified factors impacting systemwide energy use in CAV adoption scenarios.
- Developed a novel clustering of travelers into cohorts related to CAV adoption and linked that to the NHTS.

FUTURE WORK

Future work could address questions such as:

- What are the likely effects of transportation strategies on energy-use changes associated with CAV deployment?
- What are the most effective strategies to leverage CAV deployment to decrease energy use?
- How might effective strategies vary among different metropolitan regions?

COLLABORATION AND COORDINATION

Traveler behavior data
Whole Traveler Survey team (LBNL and NREL)

Statistics
Joanne Wendelberger (LANL)

Modeling discussions
MA3T (ORNL)

Workflow
SMART Workflow Task Force

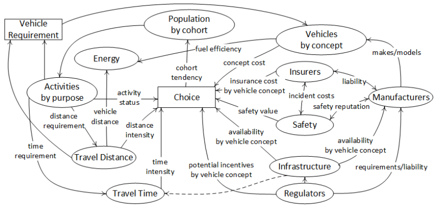
APPROACH

- Develop system dynamics simulation to model the circumstances and dynamics of transitions from predominantly individual ownership of non-CAVs to various future scenarios of high connectivity/automation.
- Identify/quantify tipping-point hypotheses.
- Evaluate known and hypothetical situations with possibly adverse effects.
- Analyze sensitivities and influences for CAV scenarios.

Dimensionality Captures Primary Differentiators

Population Cohorts	CAV/Travel Concepts	Activity Purposes
<u>Time-Sensitive</u> Value time highly and propensity for online shopping <u>Automation-Prone</u> Propensity for using automation <u>Sharing</u> Propensity for ride-hailing and car-sharing <u>Traditional</u> No propensity for automation or sharing <u>Non-Driver</u> Unable or unwilling to drive Categories have been revised based on Lawrence Berkeley National Lab's recent Whole Traveler Survey.	<u>Telecommuting</u> telecommuting substitutes for travel <u>Non-Motorized</u> pedestrian and bicycle travel <u>CAV 0–5</u> levels based on SAE International definitions: • L0 Light-duty Vehicle • L0 Transit • L0 Taxi • L0 Eco (driver feedback) • L1 Guided Busway • L1 Cooperative Adaptive Cruise Control (CACC) • L1 Urban Eco Signal Control • L4 Automated Busway • L4 Semi Fixed Route Automated Shuttle • L4 Low Speed Automated Taxi • L4 Advanced Automated Taxi • L4 Urban Freeway Automated Driving • L4 Automated Highway <u>Local Delivery</u>	Work Shopping Errands School Social Other Categories are based on the 2017 National Household Travel Survey.

Influences and Feedbacks in the CAVs Scenario Generation Model



Sector representations enable model objectives. System modeling represents influences and feedbacks that determine CAV adoption and energy consumption.

Source: NREL.

Explored Sensitivities Using Multiple Scenario-Screening Analyses

We used scenario-screening analyses to identify influential factors for CAV adoption and energy consumption.

- Screening Study (FY 17): Broad exploration of stakeholder interactions and CAV-adoption futures
- Energy Study (FY 18): Assessment of factors leading to variability in total energy consumption
- Comprehensive Study (FY 19): Quantification of interactions of stakeholder and energy factors

The three studies use Latin hypercube sampling (LHS) or Sobol experimental designs for 50,000 to 100,000 simulation runs each.

Visualization, statistical, and machine-learning techniques identified sensitivities, correlations, leverages, bottlenecks, and tipping points.

Used Multiple Studies to Explore Sensitivity to Variable Ranges

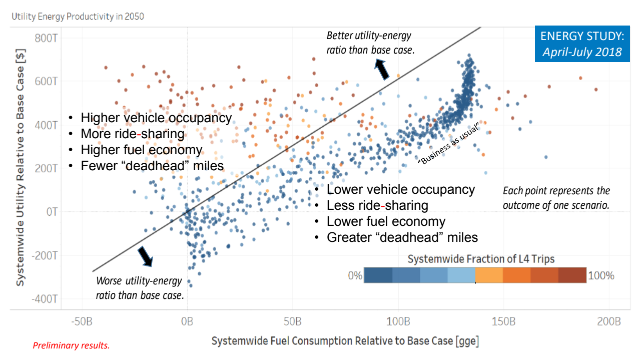
Variable	Range in Screening Study	Range in Energy Study	Range in Comprehensive Study
Value of time	$4/hr to $60/hr	$4/hr to $60/hr	$4/hr to $60/hr
Multiplier for cost of insuring CAVs	50% to 200%	Not varied	50% to 200%
Accident rate of CAVs relative to L0	20% to 200%	Not varied	20% to 200%
Consumer utility for using CAVs	-$10,000 to +$40,000	-$10,000 to +$40,000	-$10,000 to +$40,000
Variable cost of using CAVs relative to L0	-$0.50/mile to +$1.50/mile	-$0.50/mile to +$1.50/mile	-$0.50/mile to +$1.50/mile
Minimum cum. travel prior to insurance underwriting	10^8 miles to 109 miles	Not varied	10^8 miles to 109 miles
Rate of CAV cost reduction	0%/year to 20%/year	0%/year to 20%/year	0%/year to 20%/year
Initial infrastructure readiness for L4	50% to 100%	50% to 100%	0% to 100%
Fraction of passenger time freed by L4	50% to 100%	50% to 100%	40% to 90%
Valuation of safety by CAV-averse travelers	100% to 1000%	Not varied	100% to 1000%
Valuation of safety by CAV-prone travelers	10% to 100%	Not varied	10% to 100%
Multiplier for vehicle occupancy	Not varied	30% to 300%	30% to 300%
Multiplier for "deadhead" of L4	Not varied	100% to 200%	100% to 200%
Relative cost of transit to L0	Not varied	$0.25/mile to $3.00/mile	$0.25/mile to $3.00/mile
Relative cost of L0 taxi to L0	Not varied	$0.50/mile to $4.00/mile	$0.50/mile to $4.00/mile
Relative cost of non-vehicular replacements to L0	Not varied	-$10/mile to $0/mile	-$10/mile to $0/mile
Relative cost of automated highway	Not varied	Not varied	$0/mile to $3/mile
Multiplier for L4 fuel efficiency	Not varied	50% to 150%	50% to 150%

ACCOMPLISHMENTS AND PROGRESS

Results of Scenario-Based Approach

- We selected a scenario-based approach using a semi-quantitative model to explore long-term CAV adoption outcomes because the many data gaps and uncertainties regarding future travel behavior, characteristics of CAV technologies, and ownership/business models limit the validity of a fully-quantitative choice model. This approach lends itself to representing the complex CAV adoption landscape of overlapping stage gates where stakeholders block or accelerate.
- We melded results of the WholeTraveler survey that addressed important traveler behavior data gaps with results of the NHTS to synthesize traveler cohorts, trip mixes, local deliveries, and mode splits nationally and in the largest metropolitan regions.
- Scenario-screening analysis results revealed influential factors for CAV adoption and energy consumption. In particular, technological and behavioral assumptions lead to qualitatively different end states for CAVs and energy.
- In scenario-screening analyses, small changes in combinations of assumptions can rapidly separate end states of CAV adoption. Multiple evolutionary pathways can converge on similar outcomes for specific metrics, or conversely can diverge to scenarios that yield disparate mobility systems.

Identifying Leverage Points and Influential Factors for CAV Adoption and Energy Consumption Across a Range of Outcomes



Outcomes with higher "traveler satisfaction" (system-wide utility) tended to require more fuel consumption unless CAVs level 4 travel concepts predominate. System-wide utilities showed a linear relationship to fuel consumption in low L4 CAV adoption scenarios, but that did not persist at high L4 CAV adoption levels.

Source: NREL.

- Points of leverage fall into three categories: (i) necessary conditions that impede CAV adoption unless a minimally favorable threshold is present; (ii) conditions that accelerate CAV adoption; (iii) conditions not strongly affecting CAV adoption, but affecting energy use.
- The model can be used to identify the conditions necessary to reach a range of outcomes, including extremes of technology penetration. Varying assumptions regarding CAV usage may result in either very high or very low systemwide energy usage.
- Consumer preference, time valuation, and technology costs influence fuel consumption most.
- In scenario analysis results, high adoption of level 4 CAVs could be relatively rare (fewer than 30% of scenarios modeled), given wide ranges of plausible input assumptions regarding traveler propensities (ownership preference, attitude towards automation, and value of time) and technology characteristics.
- Although local-delivery concepts may shift significantly, their energy impact relative to changes in personal travel patterns remains relatively minor.

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