Model Description

By Lauren Sittler

The Connected and Automated Vehicles Scenario Generation (CSG) model is a system dynamics model. It was built by NREL and funded by the U.S. Department of Energy under the Systems and Modeling for Accelerated Research in Transportation (SMART) Mobility initiative. The purpose of the model is to simulate the “transitions from predominantly individual ownership of non-CAVs to various future scenarios of high connectivity/automation”(Bush, Vimmerstedt, and Gonder 2019). The model is organized into 12 sectors. Each sector represents an important population, process, quality, or entity involved with the transportation system. The 12 sectors are explained below.

12 Sectors in CSG

Population
Tracks population growth segmented by travel cohort and concept.

Regulation
Models the regulatory approval process for CAV concepts.

Insurance
Models the cost and availability of insurance.

Purpose
Models the frequency of travel for work, errands, social, shopping, school, other.

Choice
Calculates parameters such as cost and utility that impact consumer choice.

Safety
Calculates the safety benefit in terms of monetary value.

Vehicle
Tracks total number of vehicles by travel cohort and concept as well as total travel distance.

Infrastructure
Tracks infrastructure maturity. Calculates the effect on travel distance and time.

Manufacturing
Tracks CAVs R&D financials as well as vehicle price.

Travel
Tracks total travel distance and total travel time.

Concept Availability
Tracks whether a travel concept is available.

Energy
A stock that tracks cumulative fuel use.

Source: Bush, B., Vimmerstedt, L., & Gonder, J. (2019). Potential Energy Implications of Connected and Automated Vehicles: Exploring Key Leverage Points through Scenario Screening and Analysis. Transportation Research Record, 2673(5), 84–94. https://doi.org/10.1177/0361198119838840.

In the model, trips and travelers are organized across several dimensions, shown below.

Travelers in the model are organized into cohorts based on demographic and behavioral attributes that have been found to be linked to their travel tendencies. Definitions of cohorts are very flexible and can be tailored to specific study purposes. Default cohort definitions are shown.

Sample/Default Traveler Population Cohorts				
Time Sensitive Value time highly and propensity for online shopping	**Automation-Prone** Propensity for using automation	**Sharing** Propensity for ride-hailing and car-sharing	**Traditional** No propensity for automation or sharing	**Non Driver** Unable or unwililng to drive

The type of travel for each trip is classified by travel concept.

Travel Concept			
Telecommuting Substitute for travel	**Non-Motorized** Pedestrian and bicycle travel	**CAV 0-5** Vehicular driving, levels defined by SAE International	**Local Delivery** Commercial delivery travel within an urban area

The model also tracks the purposes of activities. These purposes can be achieved through physical movement, but some can also be met through alternative methods, such as online information exchange.

Activity Purpose				
Work	**Shopping**	**Errands**	**School**	**Other**

Source: Bush, Brian, Laura Vimmerstedt, and Jeff Gonder. 2019. “Modeling Transitions to Connected and Automated Vehicles.” presented at the Vehicle Technologies Office Annual Merit Review, Arlington, Virginia, June 10.

The system dynamics model uses arrayed variables and stocks to track quantities across each dimension.

Major Model Inputs and Outputs

Key Input Variables in the CAVs Model

- Consumer preferences
  - Level of automation
  - Value of time
- Vehicle operating specifications
- Infrastructure readiness
- Technology costs
- Insurance costs
- Travel tendencies

Key Model Outputs

- Adoption by CAV level
- Bottlenecks to adoption
- Fuel consumption
- Consumer utility

Stakeholders Represented in Model Sectors

The following stakeholders will play an important role in the adoption of connected and automated vehicles. Each stakeholder is represented in one or multiple sectors of the model.

Stakeholder	Modeling Objective
Travelers	Represent traveler preferences, value of safety, and time requirements.
Vehicle Owners	Compare alternative ownership models (e.g., Mobility as a Service).
Manufacturers	Include self-insurance during technology development and research and development (R&D) investment.
Regulators	Represent potential for regulatory lag and backlash due to safety concerns.
Insurers	Represent need for data before underwriting, discounts and surcharges, vehicle-type-specific accident rates.
Infrastructure Providers	Incorporate infrastructure constraints, investment, and development.
Energy	Account for effects on energy use.

Source: Gonder, J. (2019). Modeling Connected and Automated Vehicles (CAVs) Transitions Dynamics and Identifying Tipping Points. Presented at the U.S. Department of Energy Annual Merit Review. Project Number EEMS 064, Project ID# 7A.1.4, Systems and Modeling for Accelerated Research in Transportation (SMART) Mobility initiative. June 10, 2019. https://www.energy.gov/eere/vehicles/annual-merit-review-presentations.

Scenario Screening Analysis

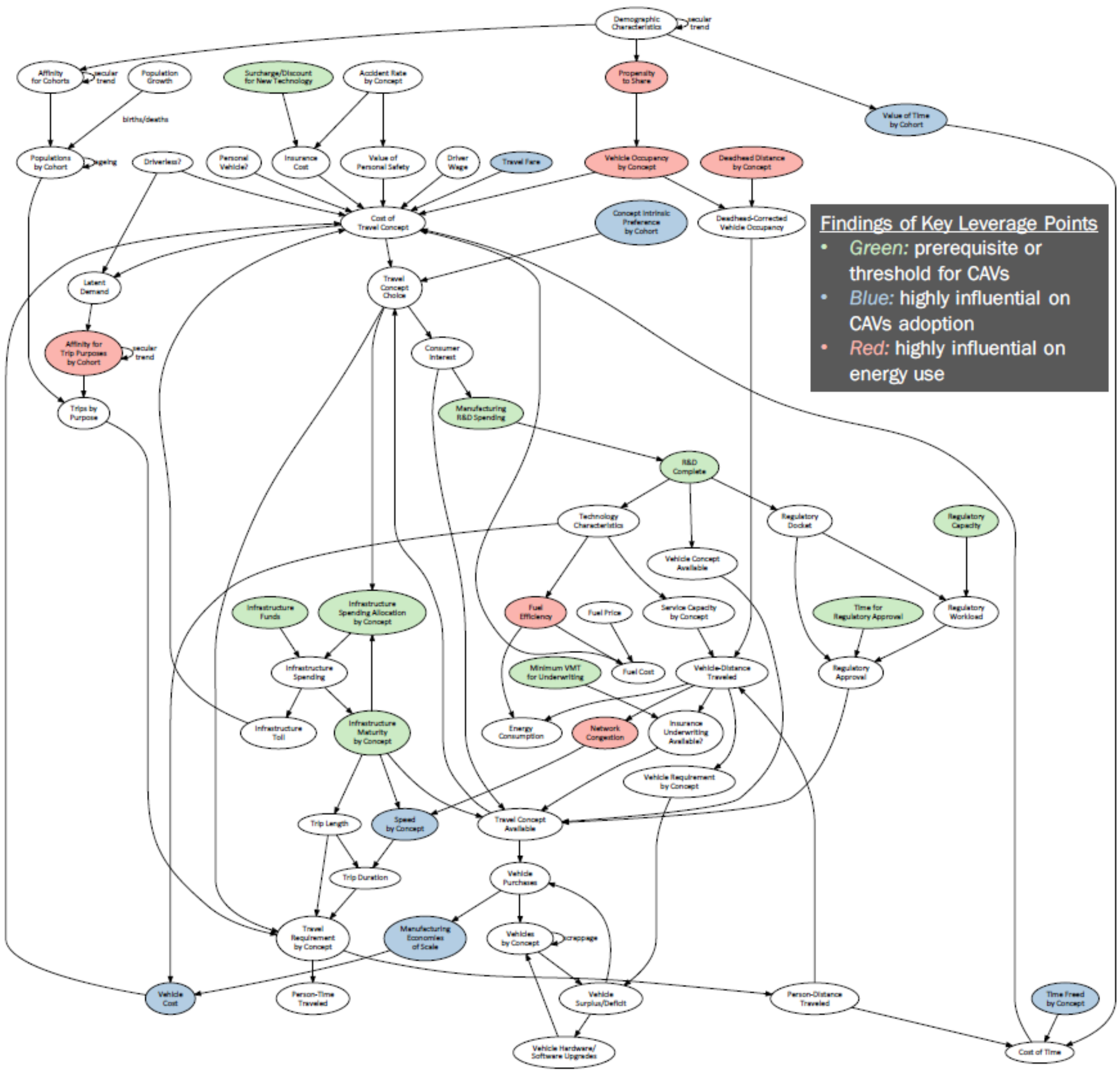
Hundreds of thousands of simulations were performed on the CAVs model in order to identify factors that were most influential on adoption and energy usage. A Latin hypercube sampling method or Sobol experimental design was used to develop the scenarios. This type of sampling was performed for the variables below over the ranges in the table.

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%

Source: Gonder, J. (2019). Modeling Connected and Automated Vehicles (CAVs) Transitions Dynamics and Identifying Tipping Points. Presented at the U.S. Department of Energy Annual Merit Review. Project Number EEMS 064, Project ID# 7A.1.4, Systems and Modeling for Accelerated Research in Transportation (SMART) Mobility initiative. June 10, 2019. https://www.energy.gov/eere/vehicles/annual-merit-review-presentations.

Key Leverage Points Identified by the CAV Scenario Generation Model

The model was tested using different sets of input conditions for cost, technological advances, and consumer behavior, collectively called scenarios. The following factors were identified as either threshold or highly influential variables for CAV adoption. Points of leverage fall into three categories: (1) necessary conditions that impede CAV adoption unless a minimally favorable threshold is present; (2) conditions that accelerate CAV adoption; (3) conditions not strongly affecting CAV adoption, but affecting energy use (Gonder, 2019). These leverage points are shown within a model schematic in the figure below.



Identification and Classification of Leverage Points in the Connected and Automated Vehicle Scenario Generation Model. Influences, leverage points, and causal relationships across the CAVs adoption system are shown, with color coding that distinguishes between necessary conditions and accelerators for adoption and energy efficiency improvement.

Source: Gonder, J. (2019). Modeling Connected and Automated Vehicles (CAVs) Transitions Dynamics and Identifying Tipping Points. Presented at the U.S. Department of Energy Annual Merit Review. Project Number EEMS 064, Project ID# 7A.1.4, Systems and Modeling for Accelerated Research in Transportation (SMART) Mobility initiative. June 10, 2019.

Publications

For additional information, please see the CSG publications:

Bush, B., Vimmerstedt, L., & Gonder, J. (2018). Analysis of Tipping Points in Connected and Automated Vehicle (CAV) Adoption Scenarios. Automated Vehicles Symposium, San Francisco, California, July 9-12, 2018. NREL/PO-5400-71816. https://www.nrel.gov/docs/fy18osti/71816.pdf.

Bush, B., Vimmerstedt, L., & Gonder, J. (2019). Potential Energy Implications of Connected and Automated Vehicles: Exploring Key Leverage Points through Scenario Screening and Analysis. Transportation Research Record, 2673(5), 84–94. https://doi.org/10.1177/0361198119838840.

Gonder, J. (2019). Modeling Connected and Automated Vehicles (CAVs) Transitions Dynamics and Identifying Tipping Points. Presented at the U.S. Department of Energy Annual Merit Review. Project Number EEMS 064, Project ID# 7A.1.4, Systems and Modeling for Accelerated Research in Transportation (SMART) Mobility initiative. June 10, 2019. https://www.energy.gov/eere/vehicles/annual-merit-review-presentations.