Project ID: VAN020

U.S. DEPARTMENT OF ENERGY
SMARTMOBILITY
Systems and Modeling for Accelerated Research in Transportation

Applied Analysis of Connected and Automated Vehicles

Tom Stephens, Argonne National Laboratory

2017 DOE Annual Merit Review and Peer Evaluation Meeting
June 8, 2017

Argonne NATIONAL LABORATORY · INL Idaho National Laboratory · BERKELEY LAB · OAK RIDGE National Laboratory · NREL NATIONAL RENEWABLE ENERGY LABORATORY

Overview

Timeline

Project start: 1 Jul 2015

Project end: 30 Sep 2018

Percent Complete: 40%

Barriers

- Large uncertainty in energy and GHG implications of connected and automated vehicles
- Need to prioritize knowledge gaps
- Need new analysis methods to address gaps

Budget

FY 2016: $450k

FY 2017: $296k 2C

–100% DOE

Partners

- Interactions / Collaborations
  – National Renewable Energy Laboratory
  – Oak Ridge National Laboratory
  – University of Illinois at Chicago
- Project lead: T. Stephens, Argonne

Relevance

Objectives

- Review relevant studies and assess what's known about potential energy and market implications of CAVs for passenger travel energy use
- Estimate bounds on the impacts of CAVs on energy use (U.S. light-duty passenger vehicles)
- Identify key knowledge gaps/uncertainties
- Develop and apply methods to estimate national-level adoption and energy impacts from local and regional results

This effort establishes a basis for prioritizing analysis of the potential influence of CAVs technologies on the U.S. transportation sector and its energy use.

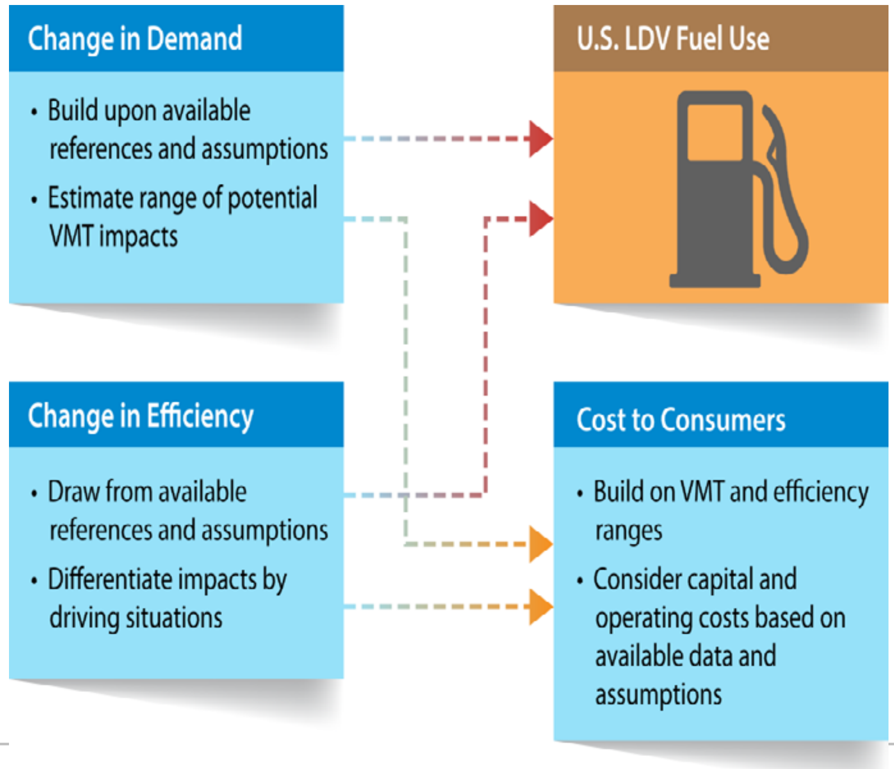
Identifying and prioritizing CAVs research and analysis needs provides a cornerstone for DOE's SMART Mobility consortium.

Milestones

Month/year	Description	Status
Dec 2015	Baseline scenario established	Complete
Mar 2016	Data gaps and key uncertainties identified for CAVs in light-duty passenger travel	Complete
Jun 2016	Prioritization matrix of knowledge gaps	Complete
Jun 2016	Establish framework for exploring uncertainty sensitivity	Complete
Sep 2016	Initial synthesis of scenarios and estimates of potential ranges of energy impacts at a national level for light-duty passenger travel	Complete
Dec 2016	Energy bounds report	Complete
Jun 2017	Report on CAVs national-level expansion methods identifying “expandable” use cases	In progress
Sep 2018	Reports on expansion/aggregation methods and adoption modeling	
Sep 2019	National-level energy impacts for multiple scenarios	

Approach: Initial literature review and assessment

- Estimate demand and efficiency impacts from 12 factors
- Calculate upper and lower bounds for fuel consumption and consumer cost
- Identify key uncertainties and directions for future research



Approach: Key assumptions

- Only light duty vehicles examined
- Fuel and powertrain switching are ***not*** included
  - Able to separate systems-level CAVs impacts from vehicle-level effects
  - Lack of studies quantifying dependence for efficiency factors
- Rely on literature inputs for bounds and baseline
  - Improvements to come from SMART Mobility studies
  - EPA MOVES; EIA data; DOT data
- Full penetration of all technologies
- No interactions/synergies between factors
- Vehicle re-design not explicitly considered
  - Right-sized vehicles to passenger load
- Roadway capacity limits not explicitly considered

Approach: Factors studied

- **Demand**
  (Changes in VMT)
  (Changes in 'mobility')
  ↑ Easier Travel
  ↑ Underserved
  ↑ Empty Miles
  ↑ Mode Shift
  ↓ Hunting for Parking
  ↓ Ridesharing

- **Efficiency**
  (Changes in MPG)
  (Changes in 'operation')
  ↑ Vehicle Resizing
  ↑ Drive Smoothing
  ↑ Platooning
  ↑ Collision Avoid
  ↑ Intersection V2I
  ↓ Fast Travel

- **Also reviewed estimated costs**

Approach: Synthesized results from literature into four scenarios

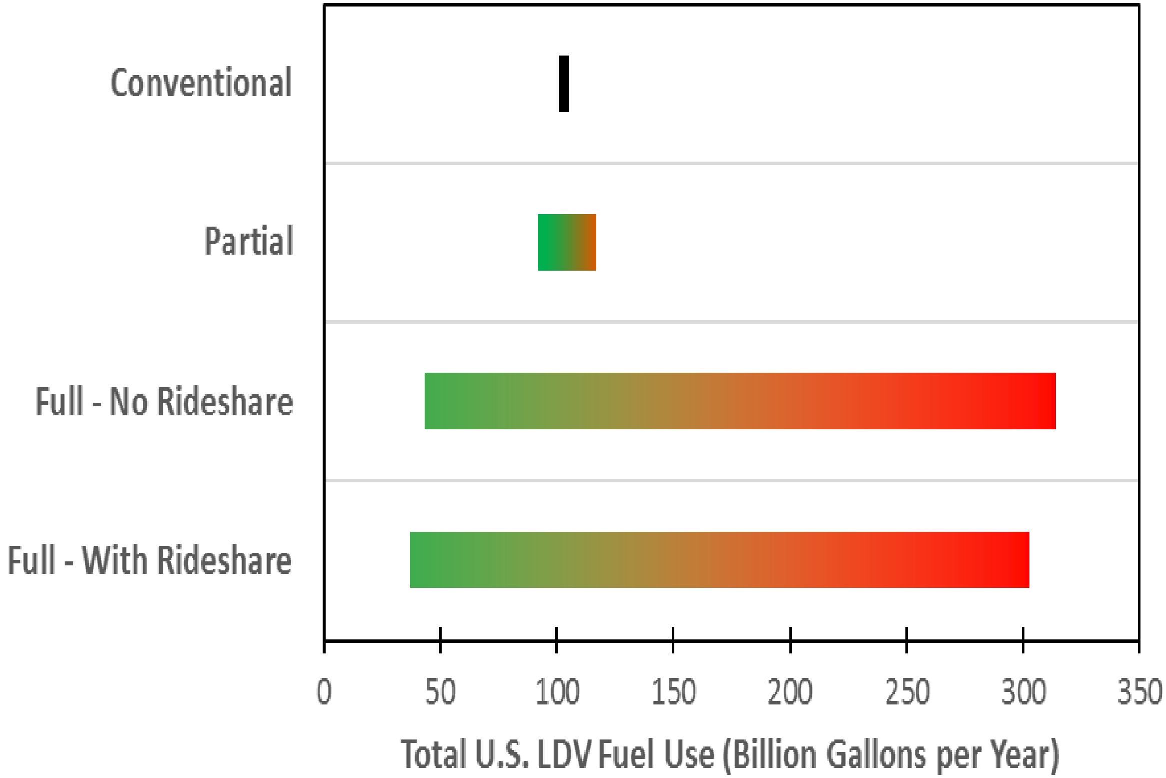
- Conventional: Negligible levels of automation and ridesharing
- Partial Automation: NHTSA Level 1&2 Automation, limited connectivity
- Full Automation: NHTSA Level 3&4 Automation, full connectivity
- Full Automation and connectivity with ridesharing

For each scenario, we estimated the range of the magnitude of each factor on VMT and vehicle efficiency considering the effect of each technology under different conditions

- Road type (city, highway)
- Congestion (peak, non-peak)

Report: Stephens et al., Estimated Bounds and Important Factors for Fuel Use and Consumer Costs of Connected and Automated Vehicles, *http://www.nrel.gov/docs/fy17osti/67216.pdf* (2016)

Accomplishment: Potential energy impacts of automation and connectivity



Partial automation:
± 10–15%

Full automation:
– 60% / +200%

Ride-sharing:
Reduction of up to 12%

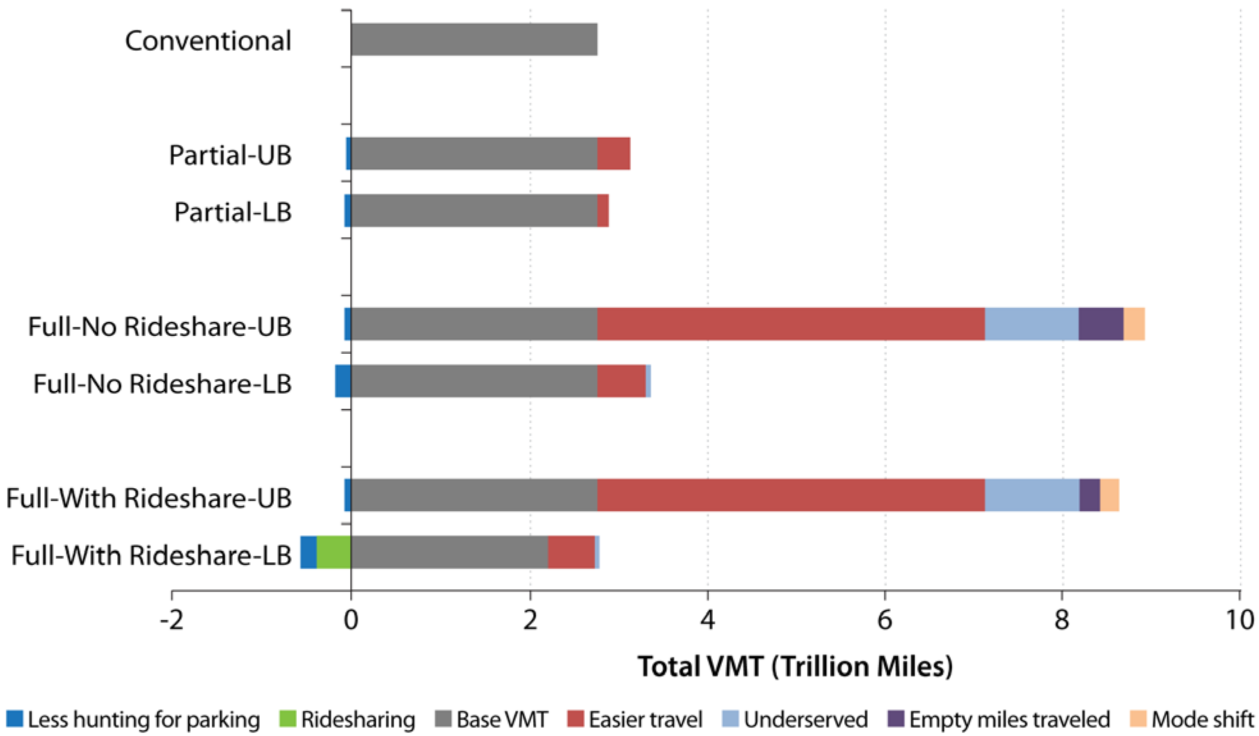
- Assuming no fuel switching nor major vehicle improvements

Results from: Stephens et al., Estimated Bounds and Important Factors for Fuel Use and Consumer Costs of Connected and Automated Vehicles, http://www.nrel.gov/docs/fy17osti/67216.pdf (2016)

Accomplishment: What drives the uncertainty in travel demand?

- **Easier travel** is a major demand driver
- **Underserved** (+access), **empty miles traveled** (repositioning), **ridesharing**, and **mode shift** are smaller important factors

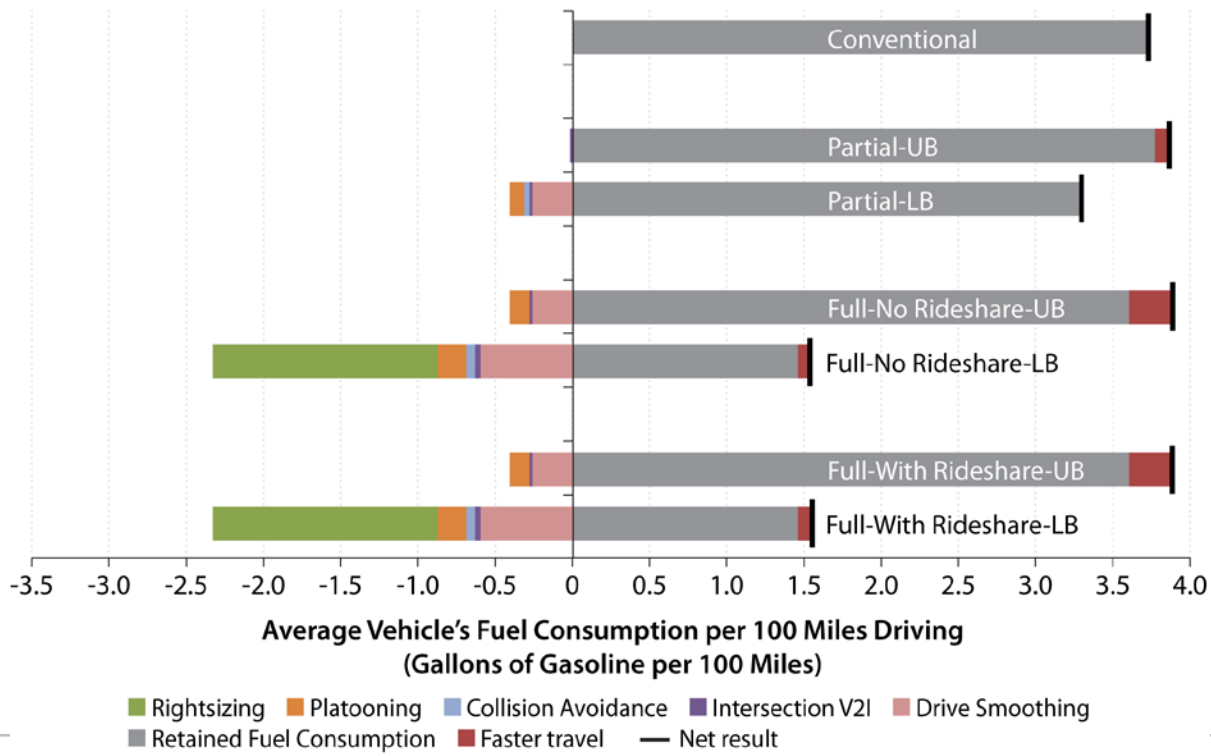
Potential national VMT under the CAV scenarios



Accomplishment: What drives the uncertainty in efficiency?

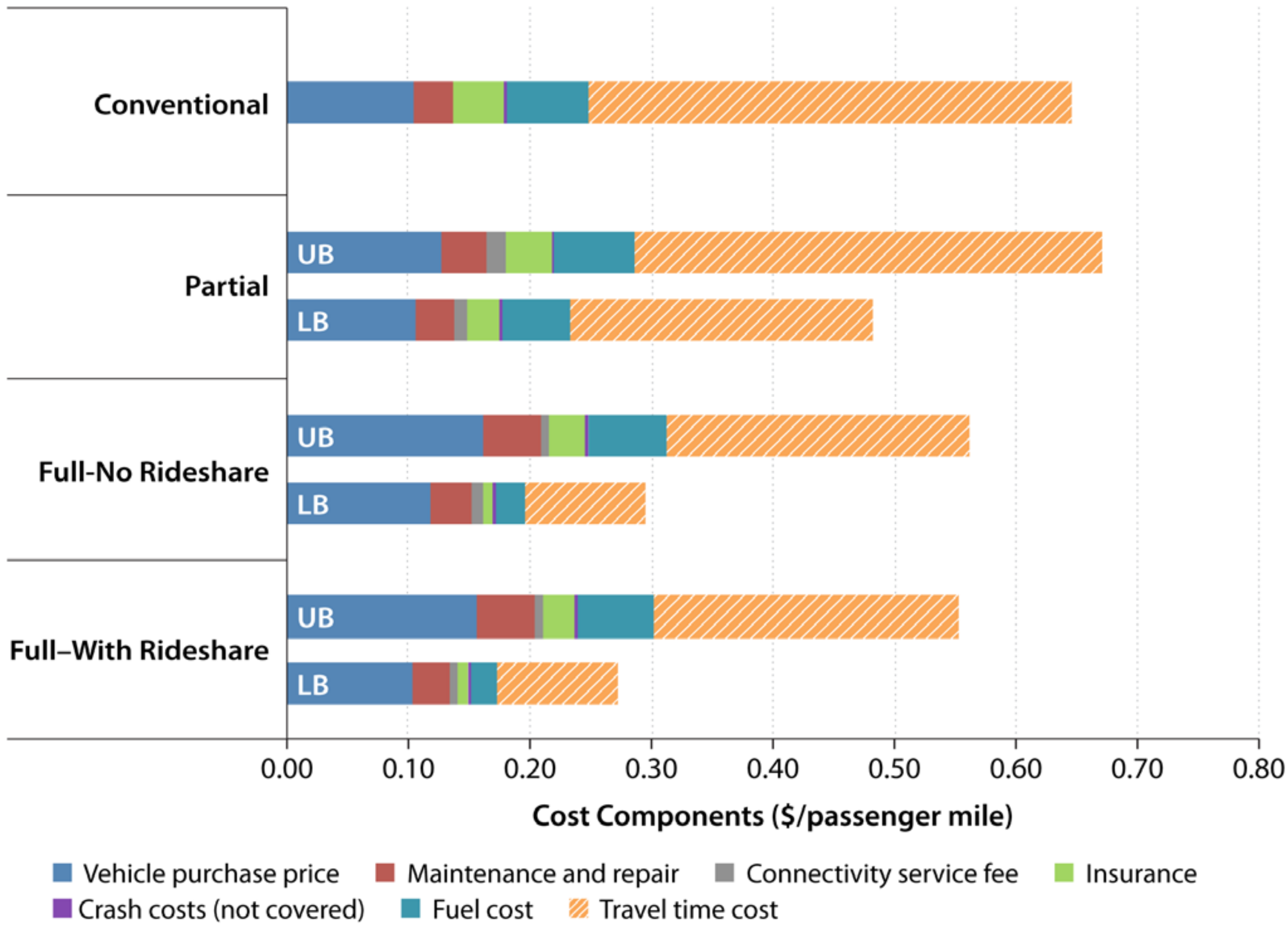
- **Right-sizing** potentially gives the largest efficiency increases
- Improved driving efficiency from **smoother driving**, **platooning**, and **connectivity** helpful as well
- **Faster (safe) travel** can potentially reduce some efficiency

Estimated bounds on vehicle fuel consumption rate



Accomplishment: What might drive adoption?

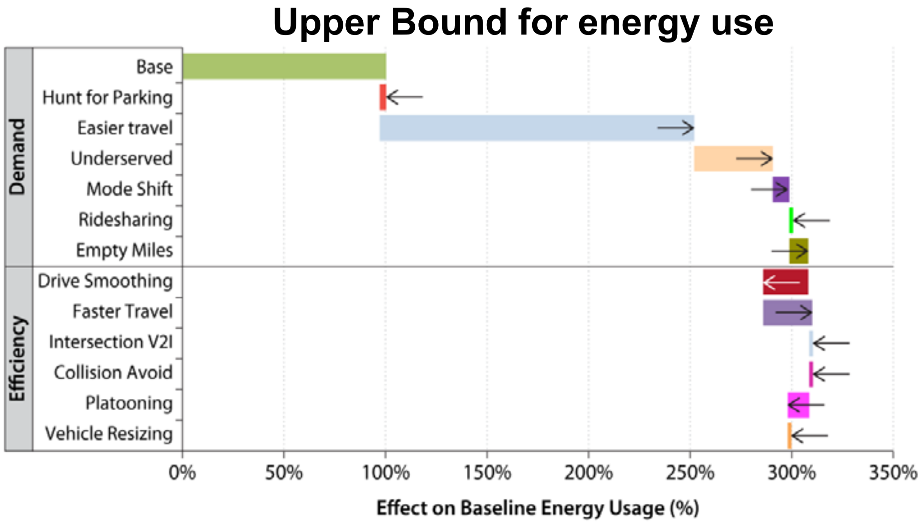
- CAVs potentially cheaper than current conventional vehicles
- **Vehicle cost** and **maintenance** higher, but **fuel costs** and **insurance costs** lower (per passenger mile)
- The **value of travel time** is a large uncertainty, potentially larger than any other economic factors

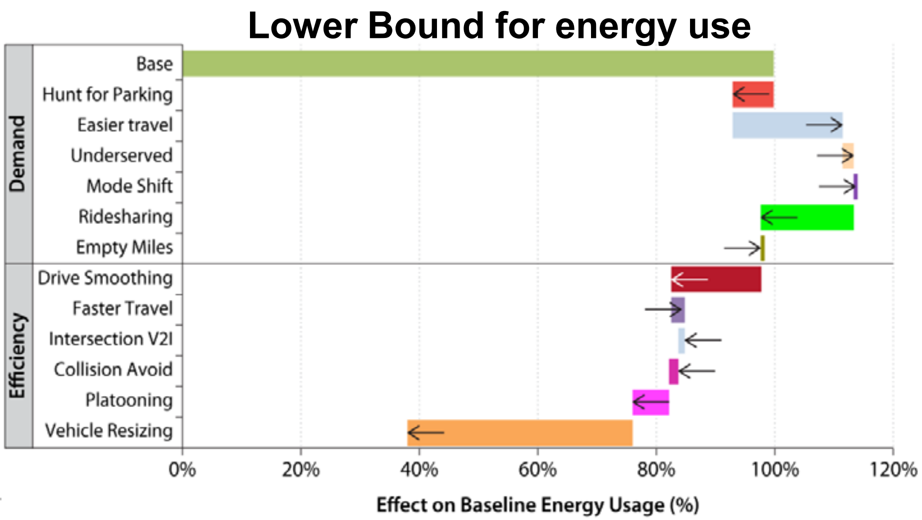


Accomplishment: What drives uncertainty? (Best and worst cases)

- Increased demand (easier travel + underserved) is key factor leading to increase in energy consumption in Upper Bound cases

- Vehicle resizing is potentially largest factor for efficiency gains; drive smoothing and ridesharing can both play large roles as well





Accomplishment: Important Data/Knowledge Gaps Identified and Prioritized

Multiple data/knowledge gaps identified under general questions

- How will travel demand (VMT) change?
- Which CAVs capabilities will be adopted at what rates by various population segments?
- How will CAVs change vehicle efficiency?
  - Light-duty
  - Heavy-duty
- How do CAVs impacts scale with penetration?

Detailed matrix with specific questions supplied to VTO

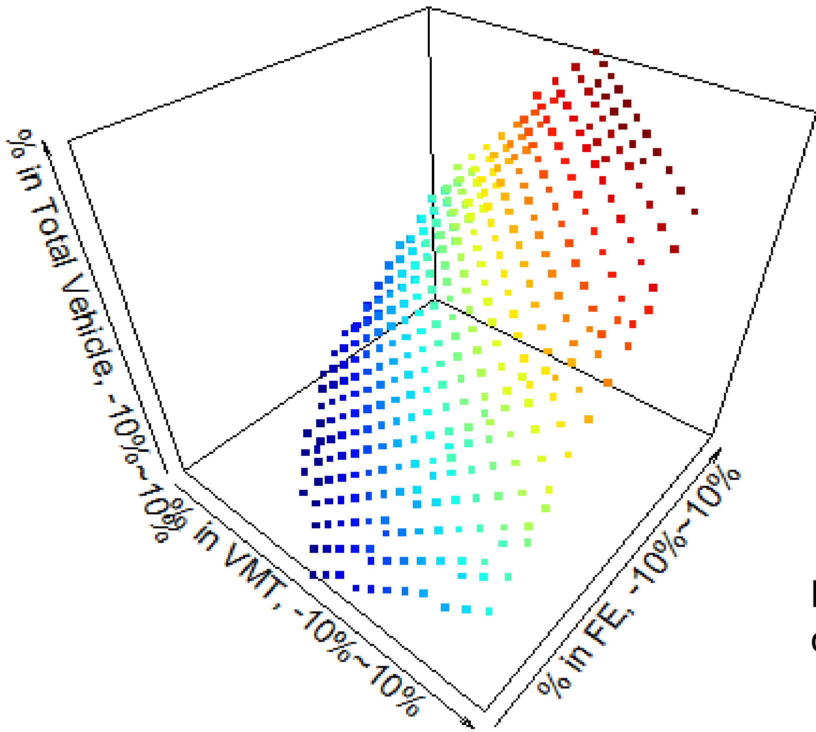
Key uncertainties in estimating potential changes in fuel use and GHG emissions associated with deployment of connected and automated vehicles				
Uncertainites (General questi	**Related questions (more specific)**	**Possible scenarios to analyze**	**Data gaps (Quantities to extract fror**	**Proposed approaches**
Light duty (passenger travel)				
How will travel demand change with CAVs?	How much empty vehicle travel due to CAVs?	Passenger travel in metro region with some fraction of partially or fully automated vehicles. Could include single technology or combinations of CACC, eco-approach/departure, coord traffic signals; both individual ownership	changes in trip frequency, distance distribution, occupancy (including empty CAVs) by demographic groups	Initially, develop approximate estimates of empty vehicle travel, induced demand (increased VMT), from literature; estimate rough bounds on potential ridesharing and mode shift from recent trends. Once transportation system simulations are available, transfer
	How much induced demand from normal & underserved population		changes in trip frequency, distance distribution, occupancy (including empty CAVs) by demographic groups	

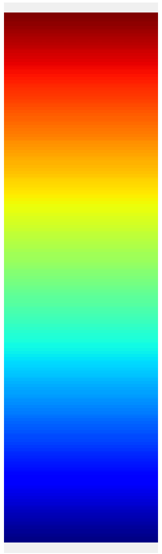
Accomplishment: Proposed Framework for Exploring Uncertainty Sensitivity

Step 1. Identify uncertainties

Step 2. Quantify impacts of uncertainties (e.g., min/max input range)

Step 3. Visualize impacts of uncertainties





Notional visualization of the impact on fuel consumption from varying input parameter values

Response to Reviewer Comments

- This project is a new start

Collaborations

- Close collaboration with the related CAVs Pillar tasks (ANL, NREL, ORNL)
  - Defining scenarios and assumptions for case studies
  - Will take results from collaborators and roll up to national level
- Informal collaborations with wider research community through TRB subcommittee and Automated Vehicle Symposium, Universities, DOT Volpe Laboratory

Remaining Challenges and Barriers

- Coordinating definition of scenarios of CAVs deployment to ensure consistency
  - Working with CAVs pillar PIs to define scenarios and use cases
- Development of analytical methods to expand local/regional simulation and modeling results to the national level
  - Ongoing effort (see EEMS026 poster)
- Development of methods to estimate future CAVs adoption
  - Ongoing effort (see EEMS026 poster)
- Application of expansion and adoption methodologies to develop national-level estimates of CAVs energy use impacts

Proposed Future Work

- Coordinating definition of scenarios of CAVs deployment to ensure consistency
  - Once highest-priority scenarios and use cases are defined, provide supporting context and assumptions (economic, demographic, transportation assumptions)
- Development of analytical methods to expand local/regional simulation and modeling results to the national level
  - Transferability methods to map changes in travel behavior from regional to national level
  - Disaggregation of vehicle energy consumption by road conditions
- Development of methods to estimate future CAVs adoption
  - Adoption modeling based on utility of CAVs vs. other choices
- Application of expansion and adoption methodologies to develop national-level estimates of CAVs energy use impacts

Summary

- Relevance
  - Provides a basis for prioritizing analysis of the potential influence of CAVs technologies on the U.S. transportation sector energy use
- Approach
  - Review literature and assess bounds of energy impacts
  - Identify and prioritize key knowledge gaps and uncertainties
  - Develop and apply methods to estimate national-level adoption and energy impacts from local and regional results
- Technical accomplishments
  - Established initial bounds on potential energy impacts of CAVs
  - Identified and prioritized knowledge gaps
  - Progress in developing expansion, aggregation methodologies and in methods for estimating potential future CAVs adoption
- Proposed future research
  - Application of expansion and adoption methodologies to develop national-level estimates of CAVs energy use impacts

Technical Back-up Slides

Demand (VMT) Assumptions and Data

- Less hunting for parking (Shoup, 2006, Brown et al, 2014):
  - 2 to 5% reduction in city VMT (peak and off-peak) with partial automation
  - 5 to 11% reduction in city VMT (peak and off-peak) with full automation
- Without considering vehicle or ridesharing, VMT impacts from CAVs (MacKenzie et al, 2014):
  - 4 to 13% increase with partial automation
  - 20 to 160% increase with full automation
- Maximum mode shifts (no shift for partial automation):
  - 0–16.4 billion mile increase in city VMT (from walking, NHTS),
  - 0–56.5 billion mile increase in city VMT (from transit, FTA)
  - 0–79.8 billion mile increase in highway VMT (from regional air, passenger revenue miles for trips < 500 mi): 79.8×10^9 PMT, BTS)
- Travel by underserved in fully automated CAVs, estimated to increase VMT
  - 2% (MacKenzie et al, 2014), 40% Brown et al (2014)
- Sharing of CAVs (auto taxis) requires repositioning of vehicles between rides
  - 5 – 11% VMT increase, without considering increased travel demand (Fagnant & Kockelman, 2014, 2015).
  - Wide range of vehicle replacement ratios: 4.4 – 11 (assumed to serve constant demand), but 4.4 was assumed with the above VMT increases to avoid extreme VMT/vehicle/yr values
- Ridesharing could reduce VMT (based on Porter et al., 2013, as cited in Brown et al, 2014)
  - 0 to 12% reduction in city VMT with full automation (average occupancy from 1.67 (2009 NHTS) to 1.9 in city area)
- Empty miles traveled by fully automated vehicles
  - 0 to 11% increase in city VMT with full automation, no ridesharing
  - 0 to 5% increase in city VMT with full automation, with ridesharing

Methodology - Energy consumption

- Disaggregate the fuel consumption into road type (highway/city), level of service (congestion/non-congestion).
- Search literature to quantify each CAV feature’s energy impact on specific road type/level of service condition under different scenarios.
- Re-calculate CAVs’ specific energy impact on applicable road type (city or highway) and condition (congested or non-congested) into aggregated national average energy impact on overall driving
- Estimate the total fuel consumption for average LDV per year with breakdown of CAV features’ impacts

Assumptions

- Average LDV annual mileage, 13350 mile/year
- Average LDV fuel economy, 26.9 mi/gal
- Gasoline price: $2.93 2010$ / gal

VMT % and fuel economy by road type and level of service

	VMT %	MPG
Highway Congested	18%	29.7
Highway Non-congested	27%	35.0
city Congested	22%	21.4
city Non-congested	33%	25.2

Based on assumptions from EPA MOVES model national default inputs and EPA fuel economy tag inputs.