Applied Analysis of Connected and Automated Vehicles

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2016 Vehicle Technologies Annual Merit Review

June 8, 2016

Washington, DC

Project VAN020

Overview

Timeline

Project start: 1 Jul 2015
Project end: 30 Sep 2018
Percent Complete: 20%

Barriers

- Large uncertainty in energy and GHG implications of connected and automated vehicles
- Lack of methods for aggregating case studies and for estimating future adoption potential

Budget

FY 2015: $140k
FY 2016: $450k
– 100% DOE

Partners

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

Objective

- Estimate potential changes in petroleum consumption and GHG emissions due to deployment of connected and automated vehicles (CAVs)
  - Develop CAV deployment scenarios
  - Define data gaps and analysis needs to direct in-depth case studies and analysis (performed under separate effort)
  - Develop methods to estimate potential CAVs technology adoption rates
  - Develop methods to aggregate results of case studies to the national level

Vehicle Technologies Office must consider the energy and emissions implications of connected and autonomous vehicles (CAVs)

- DOE EERE Vehicle Technologies Office (VTO) develops and deploys efficient and environmentally-friendly highway transportation technologies that will provide Americans with greater freedom of mobility and energy security, while reducing costs and impacts on the environment
- CAVs are may disrupt patterns of travel patterns, vehicle use and ownership, and even vehicle design with large changes in energy consumption
- Proposed analysis of CAVs under VTO-funded project “Connected and Automated Vehicles - Modeling and Simulation” (VAN022) will provide estimated energy impacts at the local and regional levels
- The results (with other results as available) must be expanded to the national level

Key questions:

- ***What are the bounds on potential energy consumption implications of CAVs at the U.S. national level?***
- ***What are the key considerations for encouraging energy beneficial outcomes and for mitigating adverse energy outcomes?***

Challenges

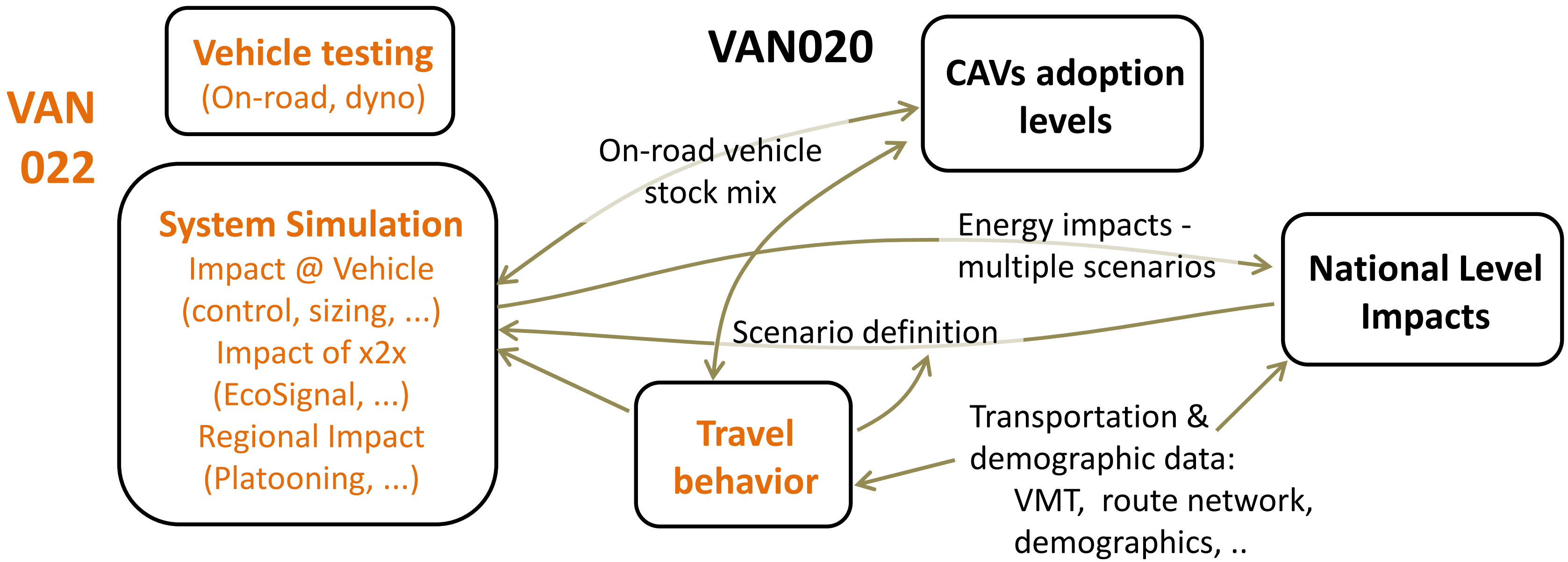
- Drawing conclusions from current literature
  - Disparate scenarios and case studies differ in assumptions and methodologies
  - Results can’t be combined or extrapolated to national level
- Estimating future adoption levels of various CAV technologies in different vehicle applications
- Taking results of simulations and analyses at a vehicle, local or regional level and expanding estimated changes in travel, fuel use and GHG emissions to the national level

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 informing CAVs focused technology demonstrations	In progress
Sep 2016	Initial synthesis of scenarios and estimates of potential ranges of energy impacts at a national level for light-duty passenger travel	In progress

Approach: Develop CAVs scenarios and analyze results from in-depth studies

- Energy impacts of CAV technologies at vehicle-, local- and regional-levels will be analyzed by the VAN022 team, with guidance on cases to analyze and assumptions from this (VAN020) effort



- Results from VAN022 analyses will be used to develop national-level estimates, to be refined as more results are available
- This effort will identify gaps and uncertainties for improved analyses by the VAN022 team

Approach: Initial literature review and assessment

- Objectives
  - Review relevant studies and assess what’s known about potential energy and market implications of CAVs for passenger travel energy use
  - Identify key knowledge gaps/uncertainties

- Scenarios considered in FY15 review:
  1) Partial Automation: NHTSA Level 1&2 Automation
  2) Full Automation: NHTSA Level 3&4 Automation
  3) Auto taxi* with no Ridesharing with full automation
  4) Auto taxi with Ridesharing with full automation

*Auto taxi = Fully automated vehicle providing transportation as a service

Scenarios Description

Scenario:	Conv-Private	Partial-Private-UB	Partial-Private-LB	Full-Private-UB	Full-Private-LB	AutoTaxi-UB	AutoTaxi-LB	AutoTaxi-Rideshare-UB	AutoTaxi-Rideshare-LB
Automation Level	N/A	Partial		Full		Full		Full	
Vehicle Ownership	Private	Private		Private		Shared		Shared	
Ridesharing	No	No		No		No		Yes	
Efficiency Improvement	N/A	Low	High	Low	High	Low	High	Low	High
VMT Demand Impact*	N/A	High	Low	High	Low	High	Low	High	Low
CAV Incremental Cost**	N/A	Low	High	Low	High	Low	High	Low	High

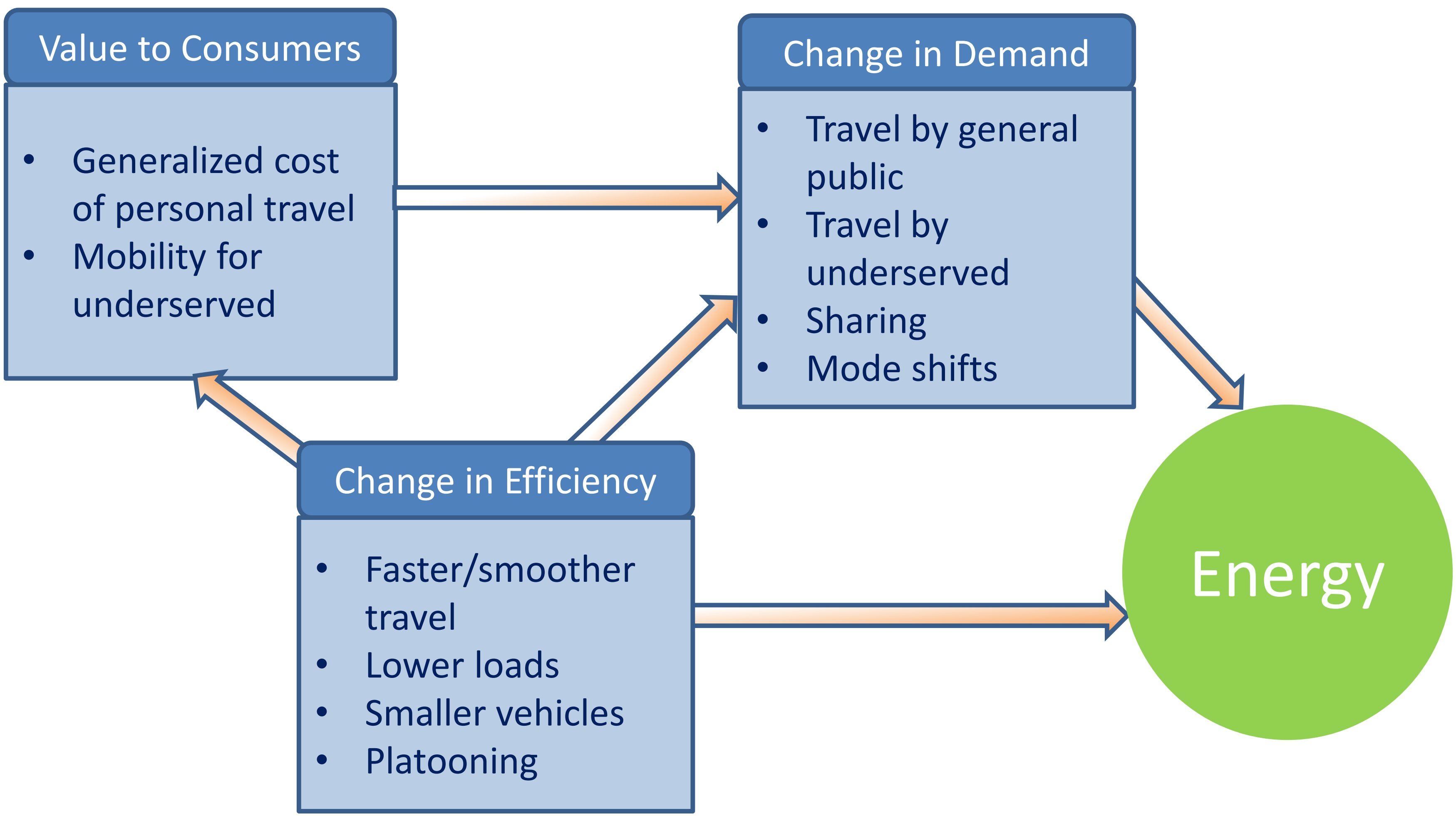
*Includes travel time costs (Low time cost leads to high VMT and thus higher energy use)

**Includes vehicle purchase cost

UB: Upper bound of energy impact (higher energy use)

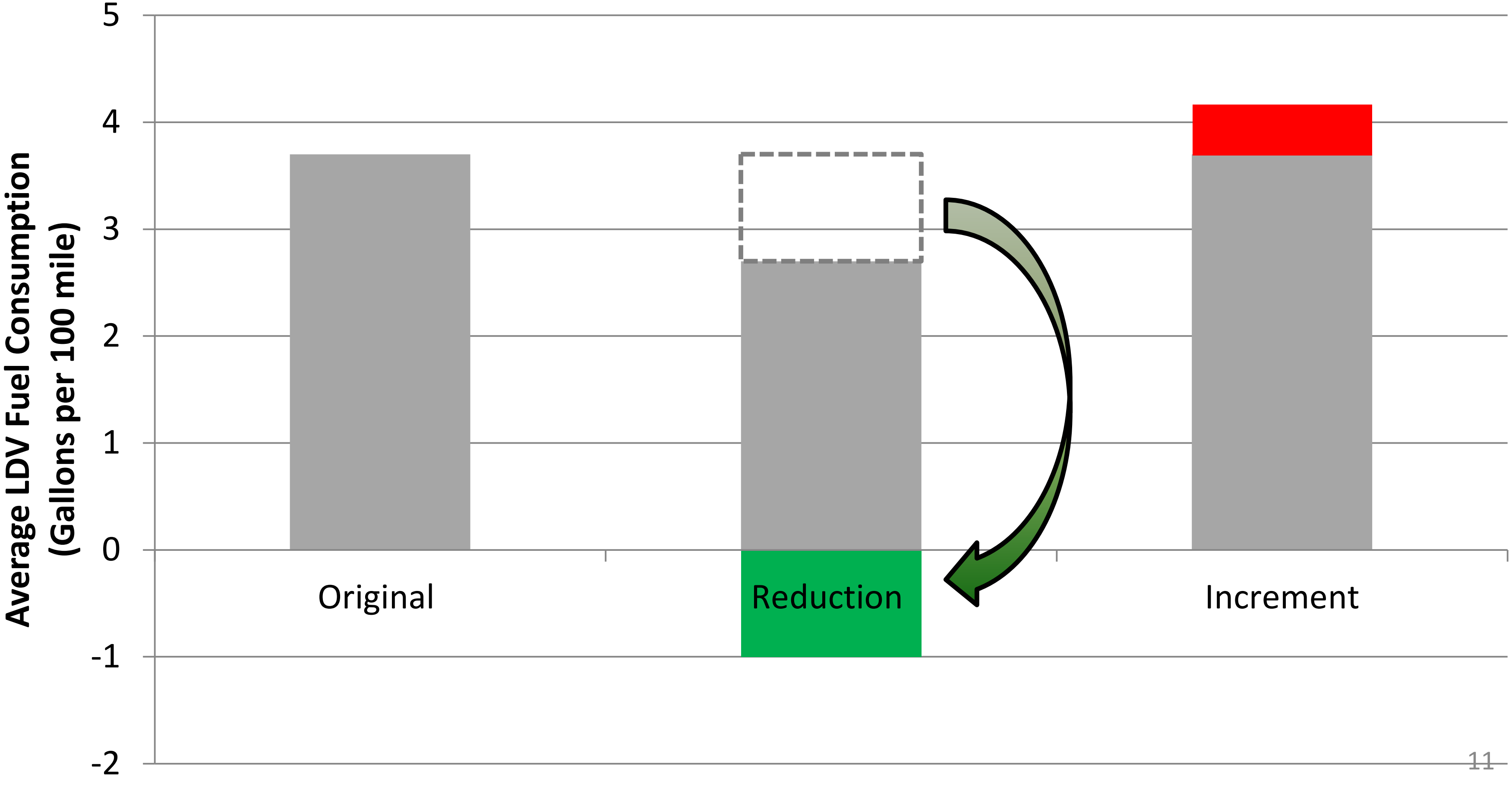
LB: Lower bound of energy impact (lower energy use)

Assessment Structure: Main factors



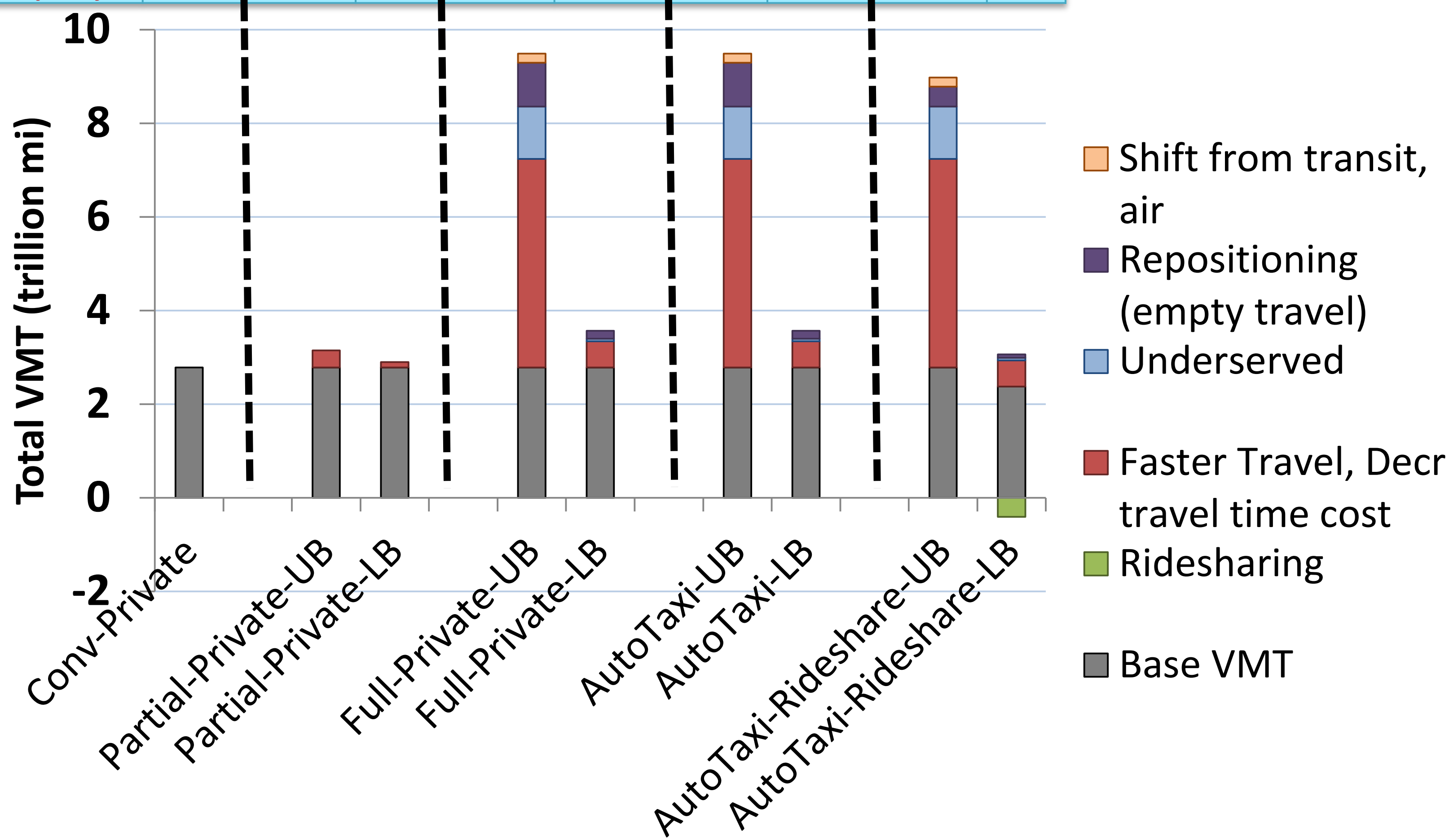
Explanation of Bar Chart Format for Presenting CAV Features' Energy and Demand Impacts:

- Reductions: for visualization, the reduction from the original attributed to each feature moves from above to below the x-axis.
- Increments: add on top of top of the original bar.
- The final height of the bar (in the positive region only) shows the net fuel consumption including all impacts



Travel Demand May Increase Significantly with Full Automation

Total VMT (Trillion)	2.8	3.1	2.9	9.5	3.6	9.5	3.6	9.0	3.1
Total PMT (Trillion)	4.65	5.26	4.84	14.27	5.67	14.27	5.67	14.27	5.67
Average Occupancy	1.67	1.67	1.67	1.50	1.59	1.50	1.59	1.59	1.85



Average Vehicle Fuel Consumption per 100 miles

Total VMT (Trillion)	2.8	3.1	2.9	9.5	3.6	9.5	3.6	9.0	3.1
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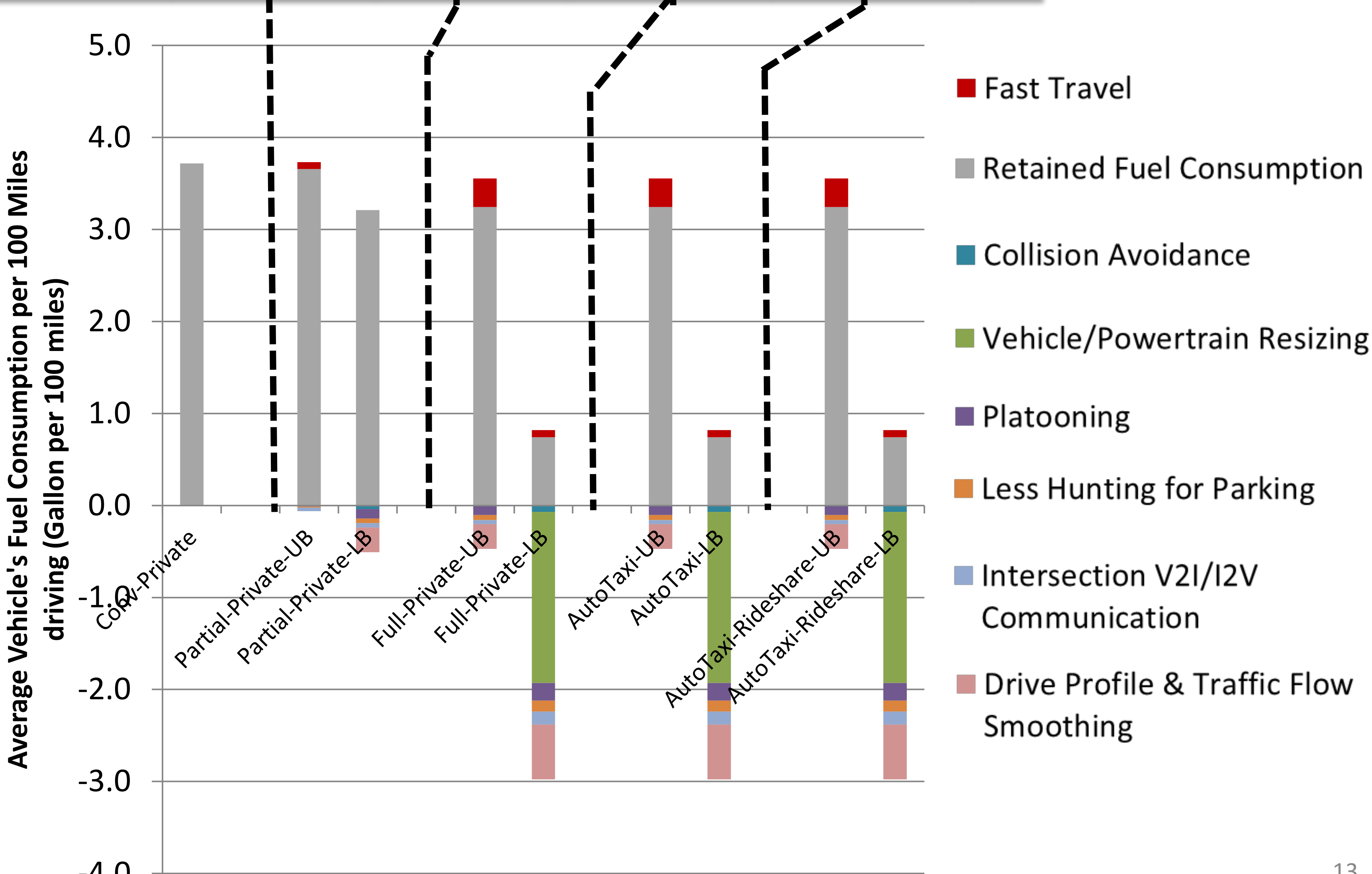

Total US LDV Fuel Consumption per Year

Total VMT (Trillion)	2.8	3.1	2.9	9.5	3.6	9.5	3.6	9.0	3.1
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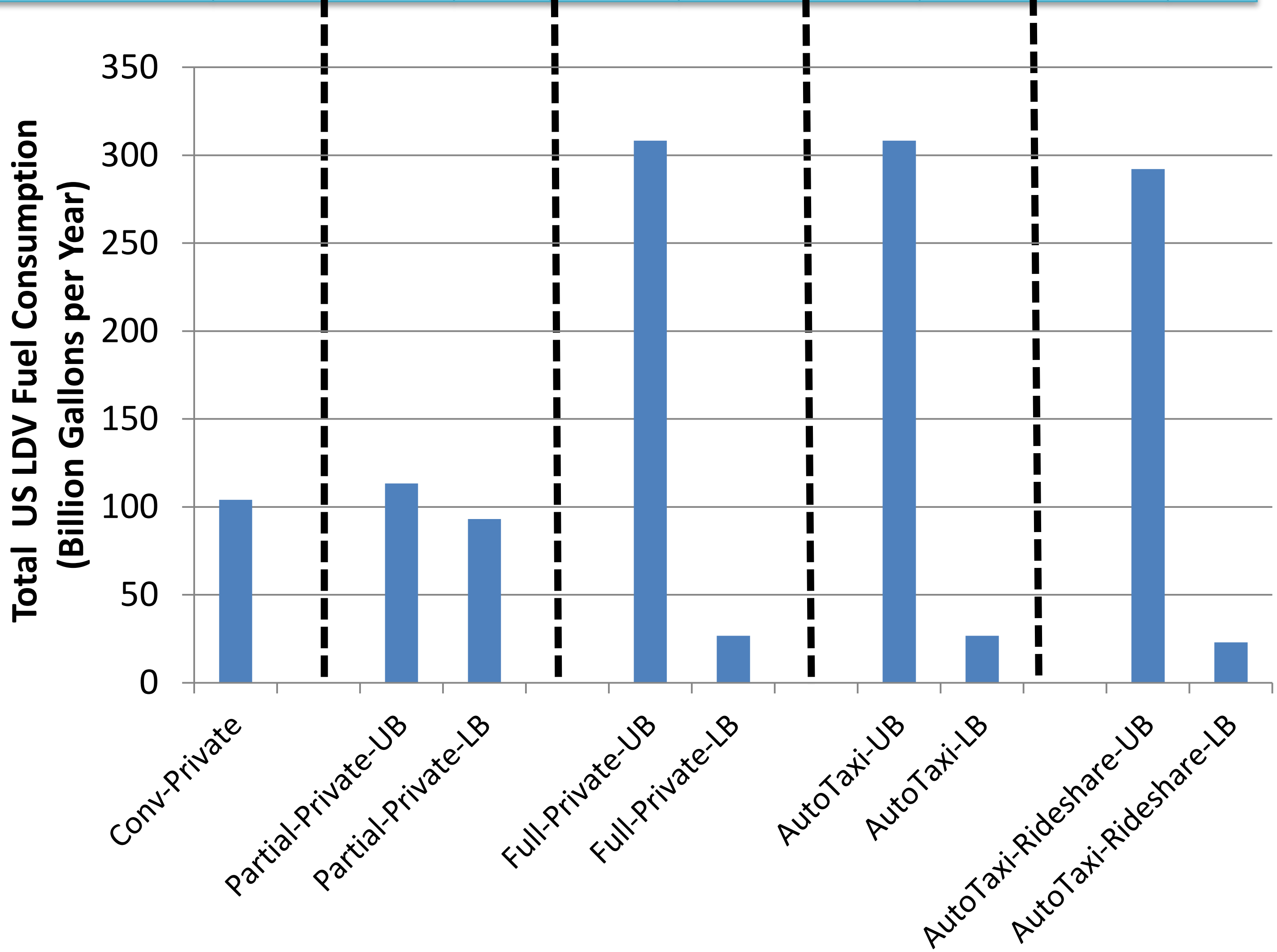
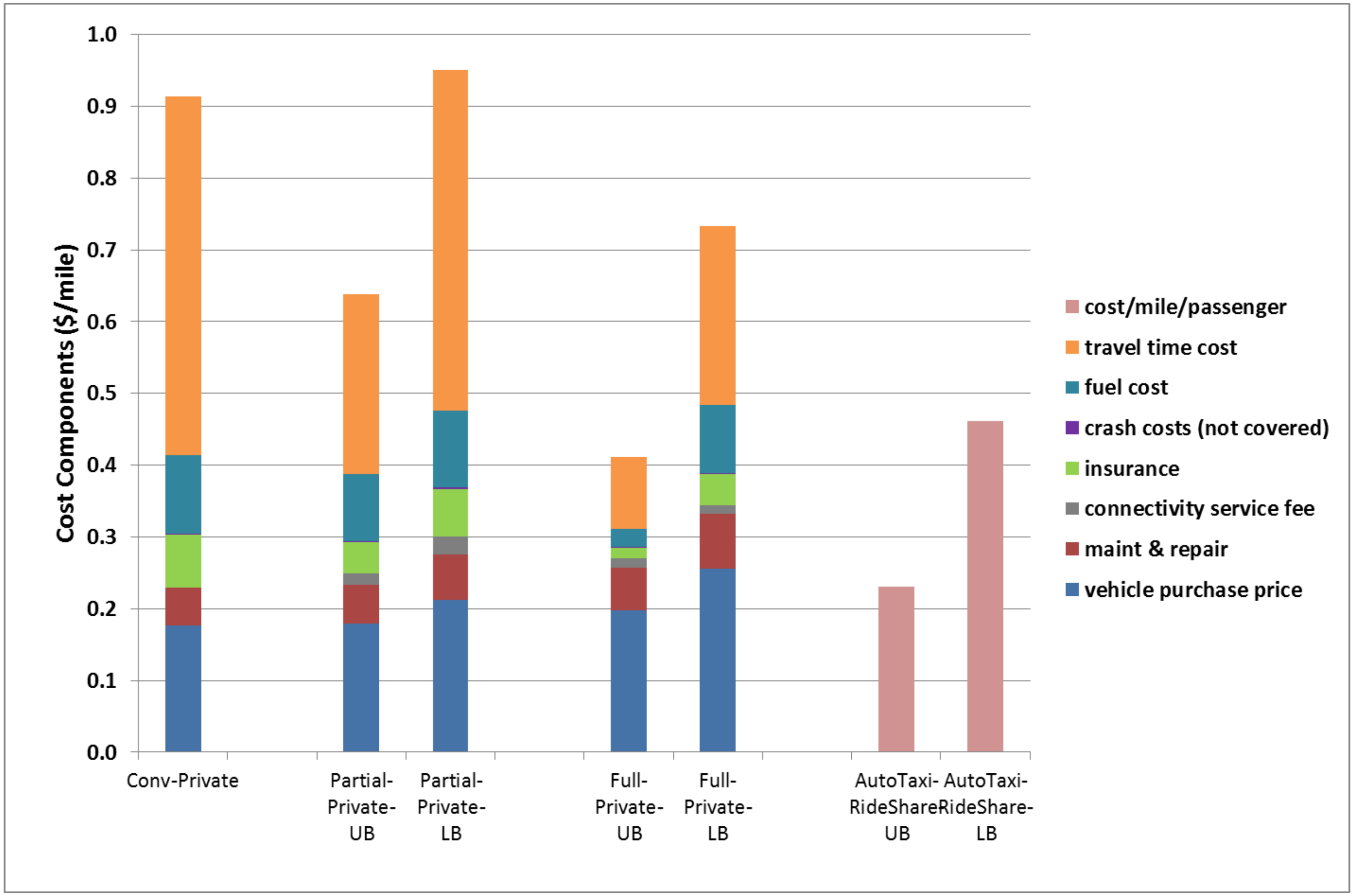


CAVS Can Greatly Decrease Per-mile Costs for LDV Consumers



- In-vehicle time value (less travel time, less stressful, more productive) likely the main selling point to consumers

Preliminary Observations and Conclusions

- Potential energy impacts of partial automation are modest (12% decr to 9% incr)
  - Due mostly to increased mobility
- Potential energy impacts of full automation are large (x 0.2 – 3), as is potential increase in economic welfare

<u>Lower Energy Bound</u>

- Low travel demand impact
- Vehicle downsizing
- Traffic smoothing
- Ridesharing

<u>Upper Energy Bound</u>

- High travel demand impact
- Faster travel
- Repositioning (empty travel)

Results: Key Questions/Uncertainties Identified So Far

Light-duty passenger travel

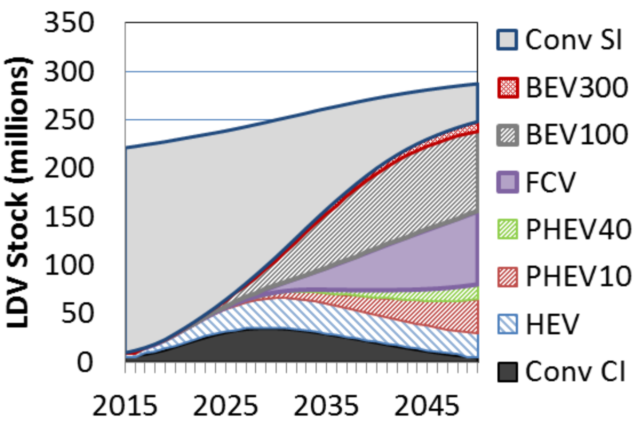
- How will travel demand change with CAVs?
  - Induced demand, empty vehicle travel, ridesharing
- How will CAVs be adopted (what technologies, what level)?
  - User acceptance, costs
- How will vehicle fuel economy change with CAVs (not including vehicle resizing/redesign)?
- How vehicles will be resized under CAVs scenarios?
- How to expand local/regional studies to national level?
  - By vehicle type & roadway conditions
  - By household

Heavy-duty vehicles

- What is energy impact of truck platooning/automation?
  - Adoption levels, fraction of truck vehicle-miles-traveled in platoons

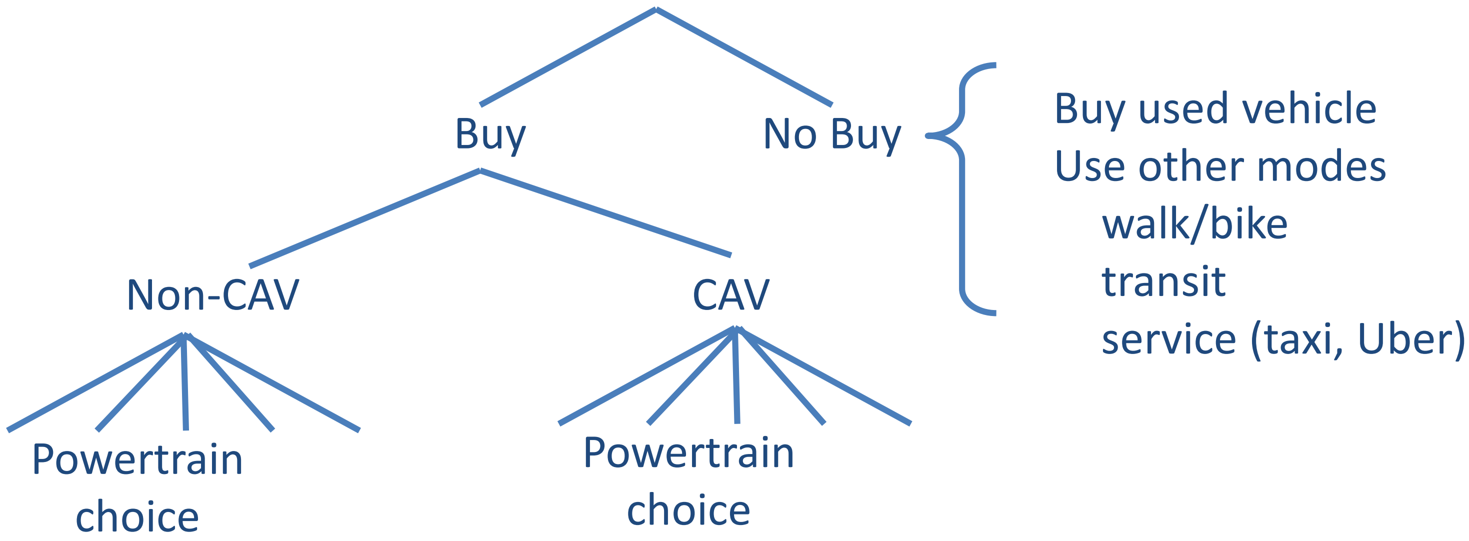
Approach: Implement value component methods to estimate CAV adoption rates

- Quantify utility to consumers within different market segments and resulting impacts on ownership and operation decisions
- Value components:
  - Stress
  - Time
  - Energy
  - Mobility
  - Productivity
- Integrate value components into ORNL's MA^{3}T model
- Revise MA^{3}T choice structure to include CAV
  - In addition to buy/no-buy a new LDV, add the options of buying a CAV and using AutoTaxis



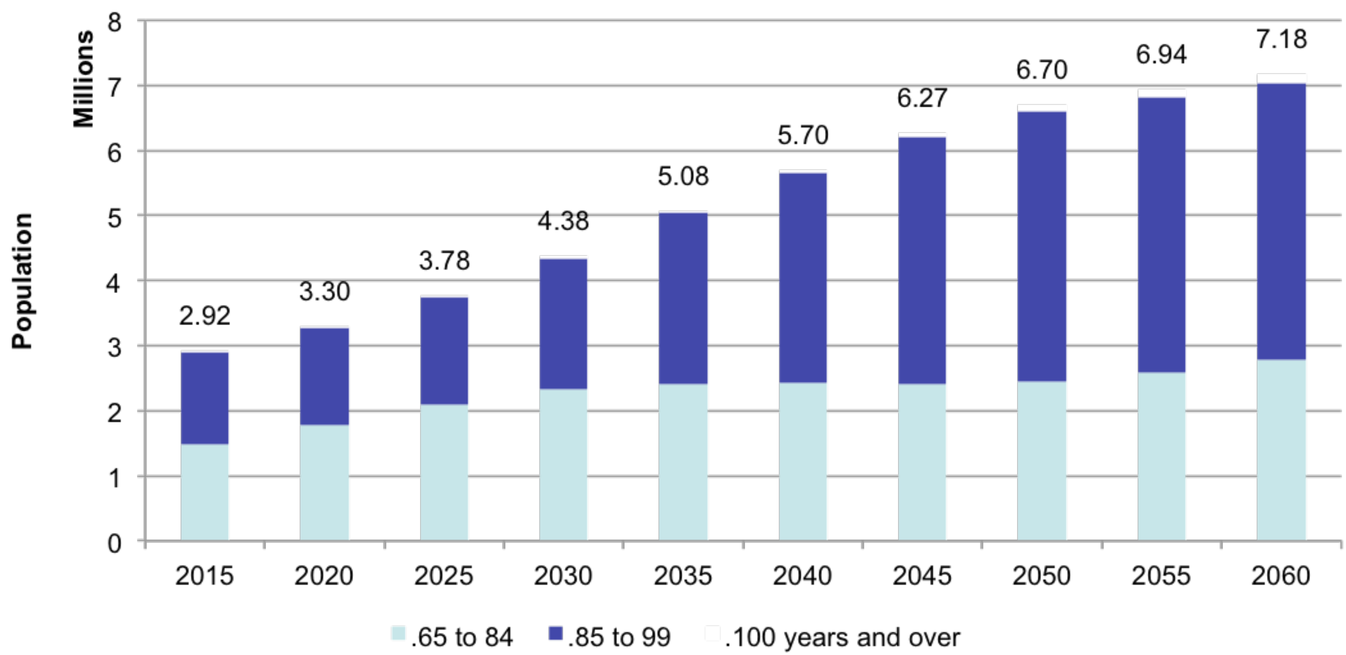
Approach: Adapt consumer choice model to include CAVs purchase decision

- The choice structure in MA3T will be expanded to include the choice of buying a new ACV and choice of modes
- Nested, multinomial framework:



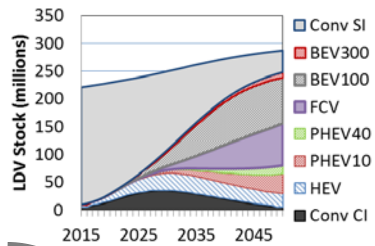
Increased demand from underserved population can be estimated from survey & census data using exogenous assumptions or economics approaches

- Harper (et al.) estimates total VMT will increase 12% due to increased demand from senior, non-drivers and people with medical conditions using 2009 NHTS data.
- Combing census data and literature on driving by elderly people, we can estimate future reduction in driving by the elderly.



Analysis framework: Conceptual calculation flows

Establish scenarios of different powertrain and CAV feature adoption rates over time

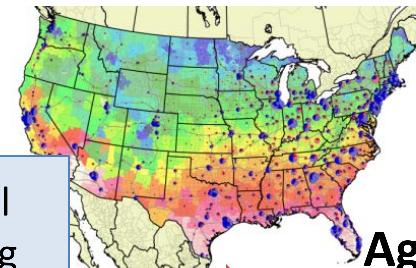


Quantify potential efficiency and travel behavior impacts of CAV features in different driving situations (9E)

2015

Calculate national-level roll up from aggregating driving situation impacts by the relative proportion of national VMT each represents

2040

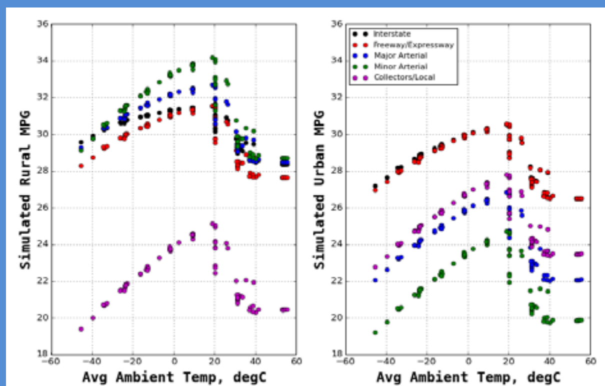


Aggregate petroleum and GHG impacts of scenarios

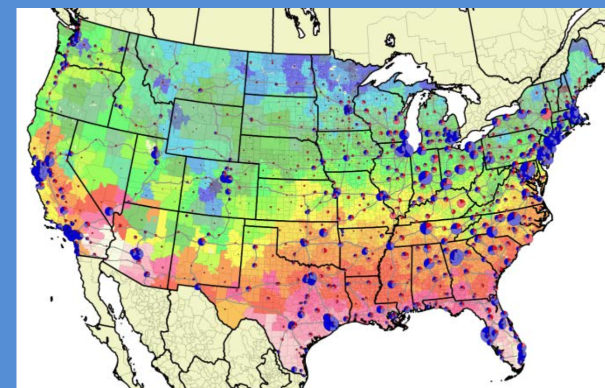
Transfer regional analyses to estimate national evolution of VMT distributions over time

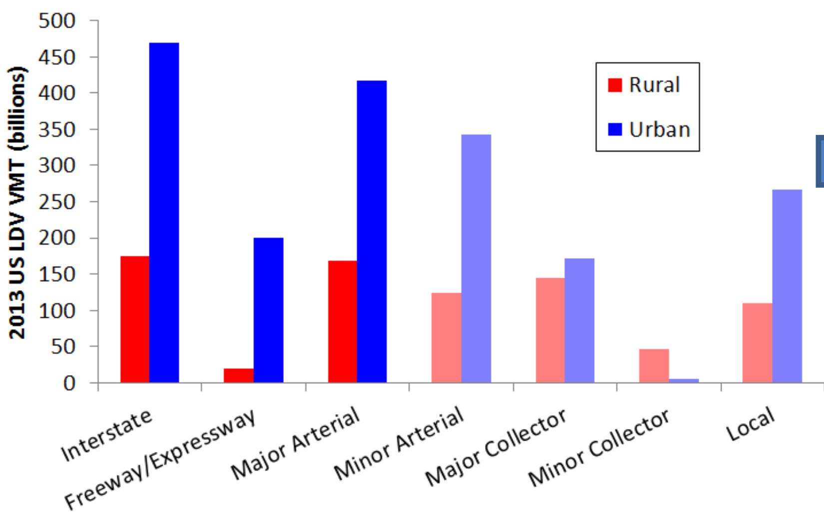
Aggregate impacts of CAV features nationally

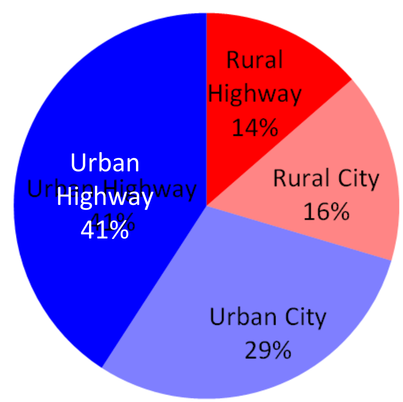
“Rates”
CAV features to provide different fuel economy benefit in different driving situations



“Volumes”
Consider the relative proportion of national VMT represented by each driving situation



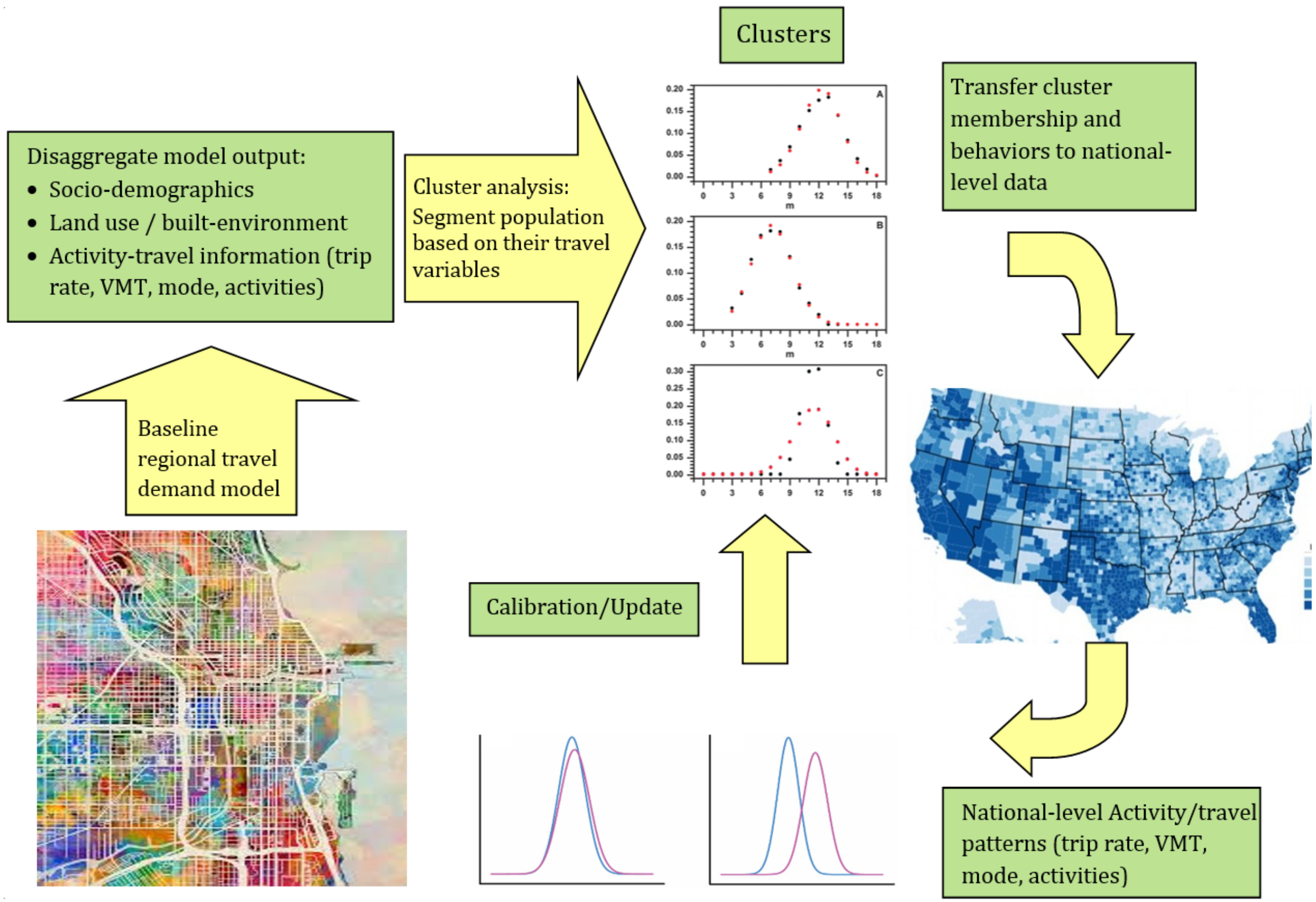




Calculate national total energy use and GHG emissions by summing VMT for the entire U.S. road network

Approach: Use transferability modeling to expand detailed travel simulation results to the national level

- Transfer results from transportation system simulations of CAVs in a metropolitan area



Transferability permits use of rich datasets to map travel patterns

- Input data:
  - Disaggregate output from Polaris transportation system simulation
  - US Census American Community Survey
  - Census 2015 TIGER/Line geographic information system (GIS) data
  - National Household Travel Survey (NHTS) 2009

- Individual-level variables:
  - Age groups
  - Gender
  - Race/ethnicity
  - Marital status
  - Education level
  - Job category

- Household-level variables
  - HH size
  - HH income
  - No. adults, workers, vehicles
  - HH members by race/ethnicity
  - HH members by educ. level
  - HH members by occupation type

Travel patterns can be transferred to households with similar characteristics

- Derive transferable variables such as total trip rates, commute distance, trip rates by various modes and with different purposes
- Cluster individuals into several homogeneous groups representing various lifestyles, utilizing rule-based Exhaustive Chi-squared Automatic Interaction Detector decision tree for each transferable variable
  - This is a flexible approach to define clusters that makes efficient use of information without requiring too many clusters
- Fitting the best statistical distribution to each one of the final decision tree clusters
- Transferring cluster membership to the national level to map travel patterns to appropriate households nationwide

Response to Reviewer Comments

- This project is a new start

Collaborations

- Close collaboration with the related VTO project VAN022 (ANL, NREL, ORNL)
  - Defining scenarios and assumptions for case studies
  - Will take results and roll up to national level
- Informal collaborations with wider research community through TRB subcommittee and Automated Vehicle Symposium

Remaining Challenges and Barriers

- Further develop expansion aggregation methods and apply these to simulation results
  - Transferability of travel patterns
  - Mapping CAV efficiency to routes throughout U.S.
- Estimating potential adoption of CAVs technologies by different population segments
- Assessing CAVs impacts in other transportation sectors (heavy-duty vehicles)

Proposed Future Work

- Expand transferability modeling to additional travel characteristics
- Estimate possible utilization of CAVs by different user groups
- Analyze potential platoon formation by long-haul trucks
- Analyze results of CAVs scenario simulations and roll up to national level
  - Connected vehicles in urban environment (traffic smoothing)
  - Connected vehicles on highways (CACC, platooning)
  - Automated vehicles in urban environment (driverless taxis, with/without ridesharing)

Summary

- The future of CAVs is very uncertain; key unknowns include impacts on
  - Travel demand
  - Vehicle use/ownership, CAVs adoption
  - Coevolution of vehicles with automation and connectivity
- Simulation and analyses of well-defined scenarios need to be synthesized into consistent, national-level assessments of potential impacts
- Important data gaps have been identified to help define scenarios and case studies to analyze next
- Synthesis approaches are being developed
  - Consumer value/adoption
  - Disaggregation by road type
  - Transfer of region-specific results to national scale
- Costs and values of CAV technologies to consumers are being used to assess potential adoption by different consumer segments
- These will connect projected outcomes to policy and technology drivers

Relevance

Approach

Accomplishments

Future work