A FIRST ORDER ESTIMATE OF ENERGY IMPACTS OF AUTOMATED VEHICLES IN THE UNITED STATES

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Summary

What we do:

- Quantitatively estimate the bounds of potential energy impacts of road vehicle automation through a variety of mechanisms.
- Combine these estimates into a wide range of scenarios to project net impacts of automation on energy consumption.

Background

- Driver-assistance technologies are already reducing driver burdens and offering opportunities for energy savings
  - Adaptive cruise control
  - Lane departure warning
  - Auto-braking
  - Fuel economy feedback
  - Parking apps
  - Navigation & traffic apps
- Full automation may amplify energy impacts – both positive and negative.
- This work explores potential energy implications of highly automated vehicles, underscoring the uncertainty and wide range of possible impacts.

Methodology

- Review popular and academic literature to identify key mechanisms through which vehicle automation may affect energy use.
- Develop bounds on these effects through literature review and first order analysis of traveler behavior and vehicle energy consumption.
- Aggregate these effects using a Kaya identity / "ASIF" approach under different 'automation scenarios':

$$\underbrace{Energy = Miles \times ModeShare}_{\text{Demand effects}} \times \underbrace{\frac{BTU}{mile}}_{\text{Intensity effects}}$$

Travel Demand Rebound Effects

<u>The value of the driver's time is the single largest cost of operating a vehicle:</u>

	Cars	Light Trucks	Heavy Duty Truck
Driver's time	$0.50	$0.50	$0.61
Wear & Ownership	$0.30	$0.43	$0.19
Fuel	$0.15	$0.20	$0.59
Insurance	$0.08	$0.08	$0.07
Maintenance	$0.05	$0.06	$0.19
Registration & Fees	$0.05	$0.07	$0.00
Parking & Tolls	$0.02	$0.02	$0.06
Generalized Cost per Mile	**$1.16**	**$1.37**	**$1.71**

<u>Assumptions</u>

- Elasticity of travel demand with respect to generalized cost: -1.0 to -2.0
- Reductions in costs through automation: low automation => low savings

	Insurance Costs	Driver's Time
Comprehensive driver assist	60%	0-5%
Full automation	80%	50-80%

- Widespread driver assist, miles traveled could increase by **4-13%**
- With full automation and energy efficiency gains, miles traveled could increase by **30-160%**

Energy Intensity Effects

Congestion Mitigation

- Reduced accident rates
- Improved traffic flow
- Eliminating congestion could cut on-road energy use by 4% in 2050

Platooning

- Platooning can cut drag by 20-60%
- Drag constitutes 50-75% of highway energy
- Highways = 40-55% of travel in 2050
- Potential to reduce LDV energy use 4-25%
- Potential to reduce HDV energy use 10-25%

De-emphasizing Performance

- Taking the driver out of the loop may reduce demand for ever-faster acceleration
- Stabilizing at current levels could cut fuel consumption 5% vs continuing historic trends
- Reverting to 1982 performance could cut fuel consumption by 23%

Eco-driving

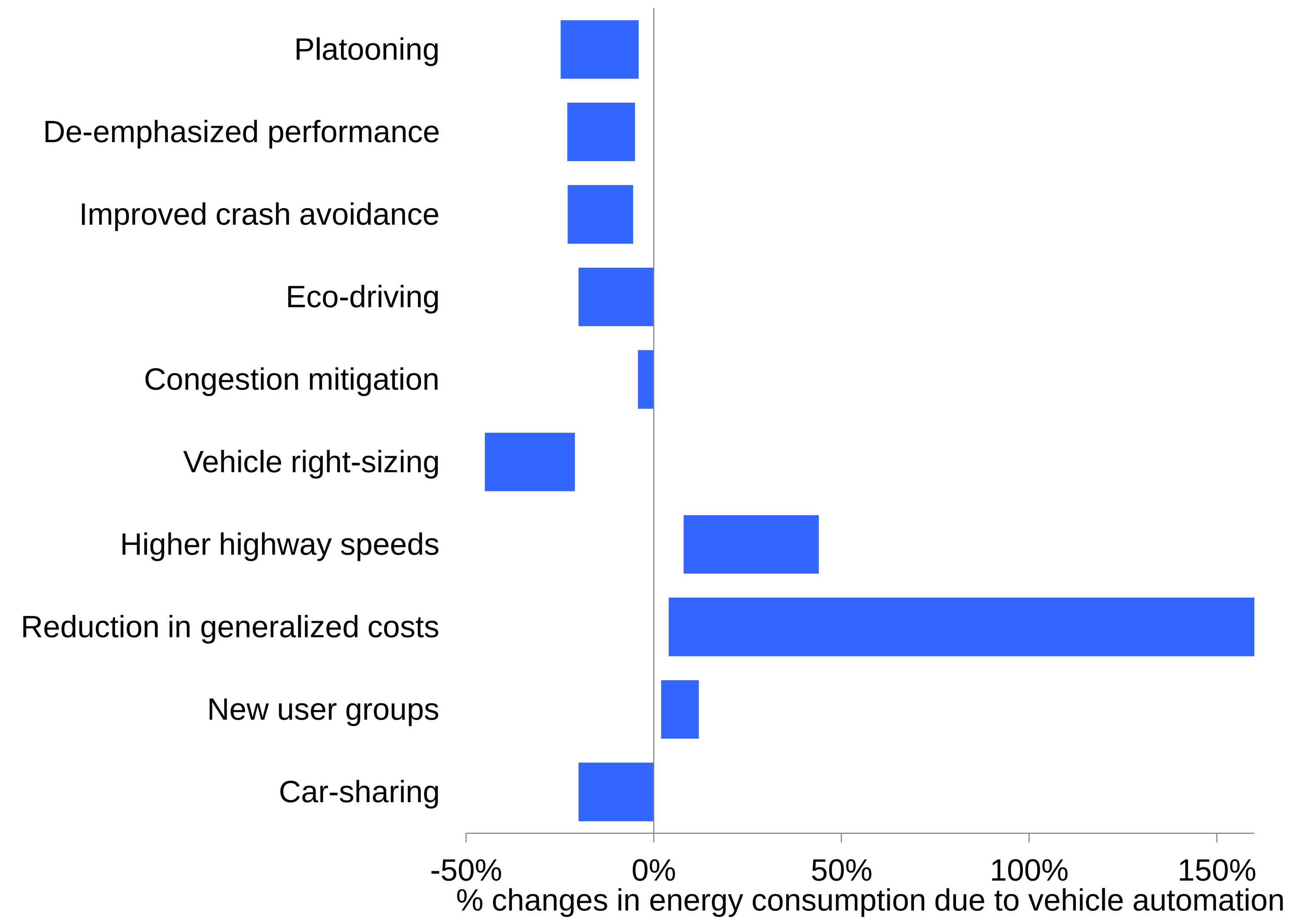
- Optimizing the time-speed trace on a route while maintaining travel time
- Could cut LDV energy use by up to 20%

Improved Crash Avoidance

- Removing safety equipment could cut weight by 8%, and fuel consumption by 6%.
- Replacing all vehicles with midsize / compact cars could cut fuel consumption by 16-18%

Higher Highway Speeds

- Automated vehicles may be able to travel safely at higher speeds than human drivers
- We assume that vehicles will travel at speeds such that the value of the marginal time saved just matches the value of the marginal increase in fuel consumption
- Travel time savings valued at $18/hour for LDVs, $25/hour for HDVs



Scenario Analysis

"Have Our Cake & Eat It Too"

Virtually all the potential benefits of automation are realized, with little of the downside. Level 3 automation enables much smoother traffic and vastly fewer accidents, all but eliminating congestion. Eco-driving is widely adopted, since it no longer relies on drivers modifying their behaviors. On highways, speed limits continue to keep traffic to about 70 mph, and platooning is widespread. With drivers out of the loop and acceleration no longer important, engine power is greatly dialed back. As accidents become a rarity, vehicles become smaller and shed safety equipment. Despite the reduction in driver burden, people cannot fully disengage from driving tasks, limiting reductions in the costs of drivers' time.

"Stuck in the Middle at Level 2"

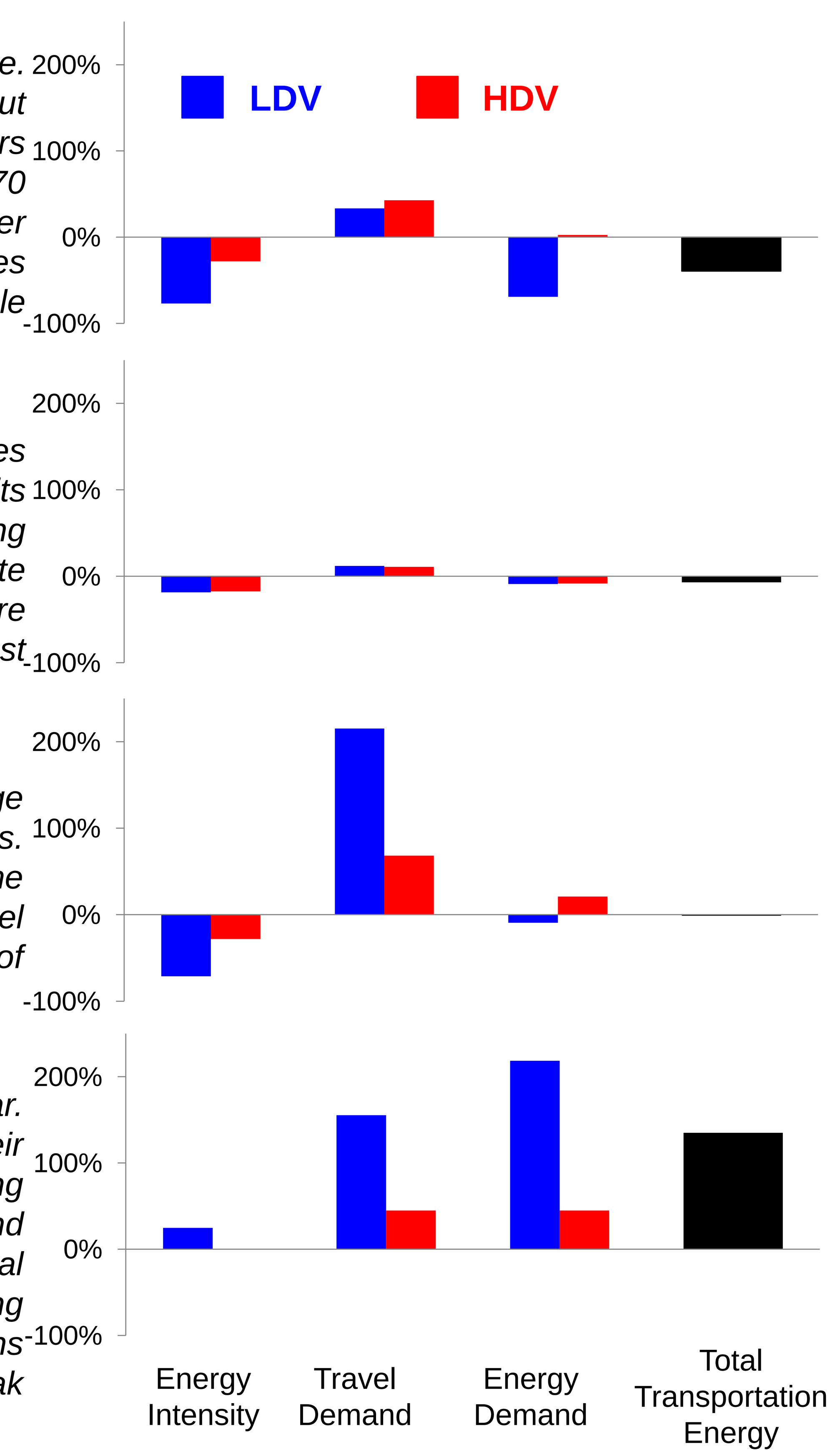
Automation advances to Level 2, but many states balk at permitting Level 3 and 4 vehicles onto their roads, effectively shutting these vehicles out of the market. Mid-range benefits are obtained from platooning (both LDVs and HDVs) and low-end benefits from eco-driving in LDVs, mainly through driver-coaching systems and energy-saving systems that operate the vehicle in select conditions. Accident rates fall, lowering insurance costs, and more elderly people drive longer, but the cost of in-vehicle time changes only slightly for most drivers.

"Strong Responses"

Automation shakes up car travel in a big way. Most of the envisioned responses are large in magnitude -- we see big operational improvements and many fewer accidents. Automated eco-driving and platooning take over, and safety equipment and power become much less important. But at the same time, highway speeds increase markedly and travel demand grows substantially due to lower perceived costs of travel. Widespread adoption of mobility-on-demand services means that vehicles are "right-sized" for each trip.

"Dystopian Nightmare"

Broad adoption of Level 4 automation totally redefines what it means to travel by car. Drivers totally disengage from driving responsibilities, and the perceived cost of the their time plummets. On the highways, vehicles travel safely at higher speeds, creating continued demand for big, powerful engines. Platooning is forestalled by a regulatory and liability quagmire, and policy inaction. In the cities, congestion relief from operational improvements is swamped by the sheer increase in traffic volume. Automated eco-driving fails to catch on, as drivers value shorter travel times over energy savings. Vehicle designs and ownership models are largely unchanged from today, as consumers buy for their peak requirements.



Conclusions

- Automation offers significant potential for reductions in energy demand and emissions.
- Reductions are not assured, since they depend on other changes in design & operations, which *may* be facilitated by automation.
- Some benefits may be realized through greater vehicle connectivity, absent automation.
- Total automobile travel demand and fuel consumption could increase, if automation reduces cost of drivers' time sharply.
- At low levels of automation (1-2), operational efficiency benefits likely outweigh increased travel demand.
- At higher levels of automation (3-4), reductions in cost of drivers' time may dominate.

Critical Issues & Uncertainties

- Value of drivers' time, and how it varies with level of automation, is critical to predicting both travel demand and highway speeds.
- Assessing how automation may open up *pathways* to dramatically different mobility models, vehicle designs, fuel choices, and use patterns.