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Event Description

The American Council for an Energy-Efficient Economy (ACEEE) organized a one-day forum on energy impacts of the connected and automated vehicles (CAVs) on May 6th, 2019 in Washington DC. The objective of the forum was to gather policymakers and other stakeholders to discuss the role of CAVs in improving the energy efficiency and sustainability of the transportation system.

CAV technologies like Tesla Autopilot, truck platooning, or driverless cars are capturing the attention of policymakers. The rapid development of these technologies and their adoption in our transportation system will have impacts on safety, mobility, convenience as well as energy use. Although the energy and environmental benefits, as of now, are secondary to the safety and mobility considerations, the policies we choose for CAV deployment will influence the magnitude of this impact.

The day-long forum aimed to identify the major players in CAV applications and deployment, and explore policy measures that could maximize energy savings while enhancing their safety and other environmental benefits. Also aimed to come to some consensus on the policy options to achieve this outcome and a research agenda to provide the information needed to further develop these options.
## Agenda

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<tr>
<td>8:00 - 8:45 am</td>
<td>Registration and Networking Breakfast</td>
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<td>8:45 – 9:15 am</td>
<td><strong>Opening Session: Keynote Address</strong></td>
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<td><strong>Welcome:</strong> Steve Nadel, Executive Director, American Council for an Energy-Efficient Economy</td>
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<td><strong>Keynote:</strong> Andrei Greenwalt, Head of Public Policy, Via</td>
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<tr>
<td>9:15 – 10:30 am</td>
<td><strong>Technology Trajectory and Characterization of Energy Impacts</strong></td>
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<td><strong>Moderator:</strong> Heather Croteau, US Department of Energy Vehicle Technologies Office</td>
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<td><strong>Panelists:</strong> T Donna Chen, University of Virginia</td>
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<td>Jean Chu, Toyota Motor North America</td>
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<td>Dovid Gohlke, Argonne National Laboratory</td>
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<td>10:30 – 10:45 am</td>
<td><strong>Networking break</strong></td>
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<td>10:45 am – 12:00 pm</td>
<td><strong>CAV applications in Goods Movement</strong></td>
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<td><strong>Moderator:</strong> Mike Roeth, North American Council for Freight Efficiency</td>
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<td><strong>Panelists:</strong> Aravind Kailas, Volvo</td>
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<td>Mark Kuhn, Ricardo Strategic Consulting</td>
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<td>Karl Simon, US Environmental Protection Agency</td>
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<td>12:00 – 1:30 pm</td>
<td><strong>Working Lunch</strong></td>
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<td>1:30 – 2:45 pm</td>
<td>CAVs in Urban Transportation Systems</td>
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|             |                                    | **Panelists:** Justin Erlich, Voyage  
|             |                                    | Art Guzzetti, American Public Transportation Association  
|             |                                    | Tom Van Heeke, General Motors  
|             |                                    | Christopher Ziemann, City of Alexandria VA  |
| 2:45 – 3:00 pm | Networking Break                     |                        |                                                                           |
| 3:00 – 4:15 pm | Policies to Promote Energy Savings  | **Moderator:** Judi Greenwald, Greenwald Consulting  |
|             |                                    | **Panelists:** Carla Bailo, Center for Automotive Research  
|             |                                    | Mark Copeland, Office of Senator Tammy Duckworth  
|             |                                    | Joshua Cunningham, California Air Resources Board  
|             |                                    | Carlos Pardo, New Urban Mobility Alliance  |
| 4:15 – 4:45 pm | Closing Session: Summary and Next Steps |                        |                                                                           |
## Participant List

<table>
<thead>
<tr>
<th>First Name</th>
<th>Last Name</th>
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<tr>
<td>Carla</td>
<td>Bailo</td>
<td>Center for Automotive Research</td>
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<tr>
<td>Peter</td>
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<td>Naomi</td>
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<tr>
<td>Leah</td>
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<td>Metropolitan Washington Council of Governments</td>
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<td>Lara</td>
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<td>Donna</td>
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<td>Kang-Ching</td>
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<td>Toyota Motor North America R&amp;D</td>
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<td>Beth</td>
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<td>Mark</td>
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<td>Heather</td>
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<td>U.S. Department of Energy</td>
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<td>Joshua</td>
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<td>Jon-Paul</td>
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<td>Mid-Ohio Regional Planning Commission</td>
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<td>Andrea</td>
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<td>Art</td>
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### Annex and slides

See attachments below for meeting presentations.
Saving Energy with Vehicle Connectivity and Automation: The Role of Policy

Briefing Paper for
ACEEE Forum on Energy Impacts of Connected and Automated Vehicles

National Press Club
May 6, 2019
Introduction

The development of connected and automated vehicle (CAV) technologies is driven by multiple considerations, especially safety, expanded mobility, and convenience. Saving energy is generally a secondary consideration, at least for passenger vehicles. Yet given the wide range of possible impacts and the imperative of reducing transport’s environmental impact in the US and globally, energy use and emissions are not secondary from a societal perspective.

The ways in which CAV technologies affect energy use are diverse, ranging from a single automation technology’s ability to improve drive train operation by smoothing acceleration, to the potential for fully autonomous vehicles to change travel habits in fundamental ways. In goods movement, CAV technologies together with automated equipment and processes could improve efficiency and save fuel by maximizing use of vehicle capacity, reducing barriers to intermodal transfers, and optimizing vehicle sizes and timing for urban deliveries.

This briefing paper cites five areas in which CAV technologies could affect transportation energy use and in each case provides examples of how policy could influence whether there will be net energy savings. Already, the inventory of potentially relevant policies and considerations is enormous. Here we provide only a sampling of issues related to energy impacts of CAVs and some possible policy responses to help orient participants to the nature of the discussion that we expect at the forum. The examples range from the technology-specific (truck platooning) to the systemwide (impacts of fully autonomous vehicles on other travel modes). When the CAV application has clear energy benefits, the policy issues discussed relate to barriers to adoption. When the application could either increase or decrease energy use, however, we focus on ways to ensure that the energy savings are positive.

For those not steeped in the subject of CAVs, here are three additional recommendations for pre-forum reading:

“A Review on Energy, Environmental, and Sustainability Implications of Connected and Automated Vehicles.” Taiebat, Brown, Safford, Qu, and Xu, 2018. Environmental Science & Technology journal paper that examines various levels of interaction between CAV technology and energy and environment. Provides a comprehensive literature review and discussion.

“Self-driving robots are the new longshoremen on L.A. waterfront.” Lippert, 2016. Seattle Times article on automation at the Ports of Los Angeles and Long Beach in the context of California’s initiatives to achieve a sustainable freight system as well as longstanding labor disputes over port automation.

Glossary

<table>
<thead>
<tr>
<th>ACC</th>
<th>Adaptive Cruise Control</th>
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<tr>
<td>AV</td>
<td>Autonomous Vehicle</td>
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<tr>
<td>CAV</td>
<td>Connected and Automated Vehicle</td>
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<td>DATP</td>
<td>Driver Assisted Truck Platooning</td>
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<tr>
<td>TNC</td>
<td>Transportation Network Company (e.g. Lyft, Uber, Via, Waymo)</td>
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<tr>
<td>V2V</td>
<td>Vehicle-to-vehicle communication</td>
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<tr>
<td>V2I</td>
<td>Vehicle-to-infrastructure communication</td>
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<tr>
<td>VMT</td>
<td>Vehicle Miles Travelled</td>
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SAE Levels of Vehicle Automation

I. Improving Light-Duty Vehicle Fuel Efficiency

State of technology
CAV technologies available today range from those providing basic information to the driver to systems that can take some level of control over vehicle operation. Many automakers are equipping vehicles with a suite of technologies. They include automatic emergency braking, adaptive cruise control (ACC), lane keep assist, traffic jam assist, automated route guidance and traffic sign recognition, and automatic high beams.

To date, the primary objective of these systems in light-duty vehicles has been to improve safety or to provide convenience to drivers. With no regulations requiring automated safety technology, consumer demand and the auto industry’s anticipation of future safety requirements is driving adoption. For example, 20 automakers, accounting for more than 99% of U.S. vehicle sales, have committed to make automatic emergency braking standard on all vehicles by the end of 2022.¹ In early 2017, USDOT proposed a rule mandating vehicle-to-vehicle (V2V) communications capability on new light-duty vehicles and standardizing the format for V2V transmissions² but has not issued a final rule.

Effects on energy use
CAV technologies can improve fuel efficiency as well by optimizing operation directly or by providing information to the driver that supports efficient operation. A system such as adaptive cruise control (ACC) can save fuel by favoring a driving style that is more deliberate and less aggressive than most humans’. ACC responds to slower traffic ahead by gradually reducing the vehicle’s speed before maintaining a set following distance. Likewise, when traffic clears, ACC accelerates in a more efficient manner than a typical driver. Highly capable ACC systems can also include traffic jam assist to provide similar benefits in slower or stop-and-go traffic, circumstances where fuel consumption is typically higher and much more sensitive to driving behavior. Driver assist systems such as predictive cruise control—currently available on some commercial trucks—can go a step further, monitoring a route’s geography and proactively changing gears and speed to save fuel.

Communications technology promises to open the door to further energy savings, once systems are in place to provide the necessary information. By communicating with infrastructure and other vehicles, a driver or the vehicle’s systems can determine when and how to adjust driving behavior. With pertinent information, the driver or automated vehicle system could maintain an optimal speed to avoid unnecessary braking and idling at red lights, make proactive lane changes to better utilize the road, or avoid an upcoming disabled vehicle or road hazard.

The promise of energy savings is highly dependent on several factors and not without its caveats. CAVs’ computing and communications equipment places additional load on the vehicle’s electrical power

system and sensors increase aerodynamic drag, all of which adds weight and increases fuel use. Furthermore, the ability of systems like ACC and connectivity to save energy is heavily dependent on the system’s opportunity to respond to cues from other vehicles or infrastructure. Hence the system must be highly capable, performing as intended, and not easily or unintentionally disabled by the driver. Some of the largest opportunities to improve fuel economy, such as mass reduction made possible by large reductions in the number and severity of vehicle collisions, will only become available once these technologies have been universally adopted. A recent analysis by Fox-Penner et al. included estimates of the various fuel efficiency impacts of CAV technologies at full adoption, as shown in Table 1.

Table 1. Estimated potential energy intensity impacts of CAV effects

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<tr>
<th>Effect</th>
<th>Impact</th>
<th>Timing</th>
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<td>Traffic Smoothing</td>
<td>−15%</td>
<td>50% reduction in technology improvements in EI for the first 10 years, then linear phase-in from 2035</td>
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<tr>
<td>Intersection Management</td>
<td>−4%</td>
<td>Linear phase-in for urban EVs starting in 2035 and fully implemented by 2055</td>
</tr>
<tr>
<td>Higher Average Speed</td>
<td>+8%</td>
<td>Linear phase-in from 2030 to 2035</td>
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<tr>
<td>Platooning</td>
<td>−2.5%</td>
<td>Linear phase-in from 2030 to 2035</td>
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<tr>
<td>Rightsizing/Weight</td>
<td>−50%</td>
<td>Phased in linearly at 1% per year or 1.5% per year starting in 2040</td>
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</table>

Source: Fox-Penner et al. 2018

Policy issues

Fuel economy standards. While automation technologies could improve the fuel efficiency of vehicles by the mechanisms outlined above, many such technologies would not be reflected in a vehicle’s fuel economy under Corporate Average Fuel Economy (CAFE) standards, because certification testing does not fully capture real-world operation. In particular, the test involves a predefined driving behavior and “route” that is designed in part for repeatability. Hence, to the extent that a CAV technology reduces energy consumption by changing driving behavior or responding to external information, its benefits will not be detected on the test.

The CAFE program grants “off-cycle” credits for some fuel-saving technologies that don’t show up in testing in order to encourage their development and deployment. If certain automated technologies were to become eligible for off-cycle credits, it could incentivize the design and implementation of the technologies to prioritize efficiency. Researchers have found that the effect of ACC, for example, could range from a 3% increase in fuel consumption to a 10% reduction, depending on the system’s algorithm for following the vehicle in front of it.

A technology can only receive off-cycle credits with a rigorous and fully documented accounting of its energy efficiency benefits, which is difficult to achieve for many CAV technologies. Stakeholders have

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suggested fixed credit amounts be considered for connectivity technologies, but EPA responded with skepticism, noting the uncertain and contingent nature of the savings. Furthermore, safety technologies are ineligible because they would be adopted even in the absence of fuel efficiency standards and hence would be “free riders” under the standards. More generally, many CAV technologies will come to market for their non-energy benefits and may not warrant incentives through the fuel economy program, especially given that such credits reduce adoption of on-cycle efficiency technologies.

*System effects.* Traffic congestion wastes more than 3 billion gallons of gasoline each year. CAV technology can mitigate congestion by reducing the number or severity of road collisions and, at high penetration, by improving traffic flow. They do not qualify for off-cycle credits under the CAFE program based on congestion reduction, however, because credits are only available for energy savings for the vehicle on which the technology is installed.

In anticipation of fully autonomous vehicles that can save energy through changes to travel behavior more broadly, stakeholders also have suggested credits for vehicles purchased for ride-hailing fleets. The rationale is that these vehicles, in addition to being fuel-efficient, would displace miles driven by multiple less efficient vehicles, given their usage and occupancy above those of privately-owned vehicles. However, there are several factors that could cause autonomous vehicles, whether personal or fleet vehicles, to cause net increases in miles traveled. As discussed in section V., this possibility is typically raised in connection with fully autonomous vehicles; but one early study showed that owners of Teslas with autopilot technology (SAE Level 2) drove significantly more than those without, taking more long trips and driving more in congested conditions.

The stringency of today’s CAFE standards is based upon federal agencies’ demonstration of feasibility using vehicle and power train efficiency technologies that provide direct fuel savings for that individual vehicle. Providing credits for technologies with indirect or uncertain energy benefits risks undermining the standards and slowing the advancement of these other fuel-saving technologies by displacing them from automakers’ compliance packages. Other policy approaches exist to promote important system effects such as ridesharing. For example, the California Clean Miles Standard promotes vehicle efficiency and higher occupancy simultaneously by setting targets for average greenhouse gas emissions per passenger mile for ride-hailing fleets.

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7 NHTSA and EPA.


II. Enabling Truck Platooning

Deployment of CAV technologies in freight vehicles is driven by energy savings to a greater degree than in passenger vehicles. Fuel is second only to driver wages among expenses for truck fleet operators.\(^{10}\) For this reason, some CAV technologies are expected to enter the heavy truck market first. Emerging technologies include predictive cruise control, eco-driving feedback systems, and platooning systems.

Platooning involves two or more vehicles following each other at close distance. Although platooning can be adopted by any vehicle type, commercial heavy-duty tractor trucks are the primary targets for this technology at present. Near-term platooning involves cooperative ACC, where the following truck maintains a safe gap with the truck in front while drivers remain responsible for steering and communication. This is called driver assistive truck platooning (DATP). Three types of in-vehicle equipment are essential for DATP: connected braking, forward collision avoidance mechanism (FCAM), and disc brakes.\(^{11}\) Connected braking is enabled by V2V communications. An FCAM system adds safety features to ACC, which uses radar to match the speed of the front vehicle while maintaining a safe gap. Disc brakes, although not dominant in trucks due to high cost, have superior performance and shorter braking distance than drum brakes.

State of technology

Technologically speaking, platooning is ready for commercialization, and truck companies on both sides of the Atlantic are participating in pilots funded by government and private organizations. Platooning is not currently in commercial use, however. Barriers include the availability of partner trucks, and state regulations requiring that drivers maintain a minimum distance from the next truck.\(^{12}\) To date, 10 U.S. states have allowed commercial DATP operations, and another 7 have authorized testing.\(^{13}\)

Effects on energy use

Platooning reduces fuel consumption by decreasing aerodynamic drag and minimizing acceleration and deceleration events. Fuel savings are strongly affected by the distance between the lead and following trucks and the speed of travel. A review of several two-truck platooning tests by the North American Council for Freight Efficiency (NACFE) showed maximum and minimum values as shown in Table 2.\(^{14}\) At a speed of 60 miles per hour and a following distance of 40-50 feet, NACFE estimated typical savings in track testing of 4% for the lead truck and 10% for the following truck, resulting in average savings of 7% relative to fuel use of trucks traveling individually. Platoons of three or more trucks could yield higher average savings.

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13 Crane et al.
Table 2: Minimum and maximum fuel savings from 2-truck platooning

<table>
<thead>
<tr>
<th>Fuel Savings</th>
<th>Lead Truck</th>
<th>Following Truck</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum</td>
<td>Maximum</td>
</tr>
<tr>
<td>2-truck platoon</td>
<td>0% at 65 ft</td>
<td>10% at 38 ft</td>
</tr>
<tr>
<td></td>
<td>2% at 49 ft</td>
<td>22% at 17 ft</td>
</tr>
</tbody>
</table>

Source: NACFE 2016.

Fuel savings also depend on the time spent in platooning, which is determined both by the availability of platooning partners and the frequency of platoon disruptions. Daimler Trucks recently announced its decision to discontinue its testing of platooning, stating that fuel savings were insufficient to make a return on investment, especially given frequent traffic interruptions.¹⁵

Policy issues

Restrictions on following distance. Platooning is currently illegal in most states, and trucking and truck manufacturing interests have pointed to the benefit of a federally-established minimum following distance that would supersede state regulations.¹⁶ As is evident from the debate over the Senate’s AV START Act in the 115th Congress, however, preemption of state and local safety regulations limiting CAV testing and deployment has been contentious.¹⁷

Platooning across fleets. Platooning today is contemplated for trucks within the same fleet. Fuel savings potential would be greatly increased if trucks were able to platoon across fleets, though compatibility issues and competition are barriers to this occurring. Steps by the government to promote the development and uniformity of the requisite communications systems and protocols, as well as sponsorship of cross-fleet pilot projects could help to expand platooning’s potential.

Highway investment. Widespread and longer platoons could rekindle interest in truck-only lanes on major highways.¹⁸ Like the debate over longer trailers and coupled trailers, such a proposal raises multiple policy questions such as whether modest improvements in truck efficiency warrant major federal investment when less energy-intensive modes including freight rail enjoy no such support and could lose business to truck platoons in some markets. While not a reason to slow efficiency gains in trucking, such considerations should be factored into prioritization of public infrastructure investment.

III. Supporting Vehicle Electrification

Vehicle connectivity and automation are often mentioned in the same breath with electrification and sharing as elements of an ongoing mobility revolution. If EVs take over the vehicle market in the coming decades as many predict, by the time fully autonomous vehicles are commonplace they also will be


electric. In the meantime, however, the two technology pathways are distinct and relate in complex ways.

State of Technology
Today, CAV technologies appear on most new vehicles, only a small percent of which are EVs. General Motors, Mercedes-Benz, Nissan, and others have introduced semi-automated driving technologies across their fleets, the majority in conventional gasoline vehicles. By 2022, nearly 100% of vehicles sold in the United States will be equipped with at least one Level 1 or higher automated vehicle technology, while EV sales will account for less than 10% of passenger vehicle sales.\(^\text{19}\)

As companies plan their roll-outs of fully autonomous vehicles, strategies on electrification diverge. Ford has announced that the AV it’s planning for a 2021 release will be a non-plug-in hybrid, while GM’s first AV, slated for production in 2019, will be based on the Bolt EV.\(^\text{20}\) Some AV startups like Zoox are developing EVs only, from the ground-up.\(^\text{21}\)

Effects on Energy Use
CAV technologies could improve the efficiency of EV operation in several ways. They could choose a route and drive cycle to take best advantage of regenerative braking and extend range and battery life.\(^\text{22}\)

To the extent that they eliminate crashes, CAVs will decrease the necessary structural strength of a vehicle, reducing material use and therefore weight. This transition to lighter vehicles ultimately will reduce energy use.

EVs are generally much more energy efficient than internal combustion engine vehicles, so CAV technologies will contribute greatly to vehicle efficiency to the extent that they facilitate the transition to EVs. Improving efficiency reduces battery requirements, which would reduce the upfront costs of EVs, making them more affordable.

In the case of fully autonomous vehicles, there are other synergies. A vehicle that can find and utilize a charging station without human involvement, for instance, would mitigate the problem of insufficient fast charging facilities. These vehicles could also time charging to minimize cost or maximize the use of electricity generated from renewables.

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On the other hand, autonomy adds to power requirements. AVs are equipped with an array of sensors and processors that at present adds around 2.5 kilowatts of electrical power demand on the vehicle.\textsuperscript{23} This could increase a vehicle’s energy consumption by more than 20% and decrease driving range by over 27%\textsuperscript{24}. Furthermore, the high cost of AVs will only compound the EV price premium, so personal autonomous EVs will likely be available only in the luxury market for some time into the future.

For this reason, the primary potential for AVs to accelerate EV adoption may arise from transportation network company (TNC) fleet purchases. Lyft has announced aggressive goals for combining the two technologies, such as providing at least 1 billion annual rides in electric autonomous vehicles by 2025.\textsuperscript{25} TNCs have a distinct advantage over households in their ability to amortize the cost of an autonomous EV over a high number of miles driven. When purchased for fleet use, an EV’s lower operating costs from both fueling and maintenance will offset its high upfront costs. Full autonomy will easily pay for itself in fleet service by eliminating the cost of a driver. Autonomous EVs in fleet service will also facilitate optimization of vehicle usage by deploying vehicles appropriate for the distance and capacity requirements of each trip. EVs also pose challenges for fleets, however, such as the cost of removing vehicles from revenue service to charge for extended periods, perhaps multiple times daily.

**Policy Issues**

*Vehicle Miles Traveled.* Concerns that AVs may result in more miles driven has generated calls for mandatory electrification of AVs. This would increase EV production and offset some of the emissions impacts of increased vehicle miles traveled (VMT) but raises other issues, including the non-emissions costs of higher VMT and equity of access to advanced technology vehicles. TNCs, which have built-in incentives to pursue AVs, could be encouraged to ensure that those vehicles are EVs as well. The California Clean Miles Standard cited in section I. promotes both electrification and shared rides in TNC vehicles.

*Incentives for EV efficiency.* Various policies to incentivize EV adoption today take no account of EV efficiency. Federal tax credit amounts are based on battery size, and vehicle standards artificially elevate EV performance to incentivize their adoption. Manufacturers might prioritize CAVs’ contributions to EV efficiency if policies took EV efficiency into account.

**IV. Advancing Efficiency of Goods Movement**

Ports and other intermodal facilities are prime targets for automation, along with a host of other advanced technologies, including “connected platforms, cloud-based services, mobile devices and apps, sensors and other Internet of Things technologies, augmented reality, autonomous transportation,


\textsuperscript{25} Coplon-Newfield, G. 2017. “Lyft will provide 1 billion automated electric car rides per year by 2025.” Sierra Club. Blog post. \url{https://content.sierraclub.org/evguide/blog/2017/07/lyft-will-provide-1-billion-automated-electric-car-rides-year-2025}. 
blockchain technology, and big data.” Much of the automation at ports involves stationary equipment, but connectivity and automation of vehicles is necessary to take full advantage of the efficiency opportunity. Automation can improve the sequencing and timing for pickup and drop off. While institutional and business barriers may remain to “collaborative shipping,” in which unrelated or even competing companies share space in the same truck or rail car, automation can help to remove the logistical barriers to such collaboration and other practices to increase vehicle load factor. Fully autonomous vehicles will become a reality at ports sooner than they can serve as general-purpose trucks, due to the limited range of operating conditions within a port.

The Vera autonomous vehicle, for trips within freight facilities. Source: Volvo Truck Corp.

State of technology
Automation has been an aspiration of ports and other intermodal facilities for decades and has been implemented to a degree in several locations around the world. An explicit European Union objective of reducing emissions from freight movement is driving progress in European ports. Rotterdam is at the forefront of multiple efforts to reduce GHG emissions. Its port has five automated deep-sea terminals and is a pioneer in “synchronomodality”—the dynamic, real-time assignment of containers leaving the port to any of several modes, depending on which offers greatest efficiency and lowest cost. A facility described as the world’s first fully automated intermodal terminal has been contracted for Sydney, Australia. Automation and connectivity are generally less advanced at U.S. intermodal facilities, but

Examples do exist. The Los Angeles/Long Beach port complex has automated yard operations in two terminals: Middle Harbor in Long Beach and TraPac in Los Angeles.29

Effects on energy use
Like on-road applications of CAV technologies, automation at intermodal facilities is driven by multiple objectives. In this case, reducing energy use aligns with cost savings, space optimization, and operational efficiency. Automation of vehicles and equipment in these facilities could reduce energy use and emissions in at least three ways. First, streamlining cargo handling will reduce idling and distances traveled by equipment on site. Second, connectivity and automation technologies can optimize the dispatch and loading of drayage30 trucks and other vehicles that access the facility, reducing congestion and minimizing empty backhaul and partial loading. And third, these technologies could facilitate the use of energy-efficient modes such as rail and short sea shipping to carry cargo to a port by consolidating loads across carriers cutting the cost in time and labor of transferring goods from one mode to another at access these non-truck modes.

Policy issues
Jobs. Automation of heavy-duty vehicles and equipment may threaten operators’ jobs. Some argue that long-haul trucking, which is likely to be the earliest application for fully autonomous on-road vehicles, is a highly stressful occupation that today struggles to find drivers, and that replacing those positions with more jobs for short-haul drivers who can return home at night would be a net gain. For intermodal facilities and at ports in particular, however, labor disputes arising from automation are longstanding. The International Longshoremen’s Association has not accepted automation of horizontal transport at East and Gulf Coast ports,31 and recent proposals for additional automation at the Port of LA/Long Beach have proven highly contentious,32 however, and the longshoremen’s association State and local government will need to anticipate and help to broker equitable resolutions of such conflicts if such projects are to succeed.

Multi-stakeholder cooperation. Competing interests at ports, within and across industries, pose an obstacle to realizing the full potential for automation to achieve efficiencies, and the attendant economic and environmental benefits. Even at West Coast ports, where terminals are affiliated with an ocean carrier, multiple landside transportation providers must interface with port operations. If the efficiency benefits of automation were to extend to shippers and carriers in their off-port transportation and logistics operations, the high costs of automation could be distributed more broadly as well. Overcoming these obstacles would also provide large air quality and health benefit in and near the port, and this should be considered in evaluating the cost-effectiveness of automation. State and local government participation is essential to reduce the barriers to cooperation across the various stakeholders and competing parties in the port setting and at other multimodal facilities. Governments

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30 Drayage is the transport of goods over a short distance in the shipping and logistics industries.

31 Mongelluzzo.

could also advance such projects by ensuring compatibility of equipment and standardization of communications protocols. In California, the governor floated ideas such as subsidizing semi-autonomous trucks, giving such trucks preferred access to facilities, promoting mobile-app-based services that help optimize less-than-truckload freight movement, and capping emissions at the terminal level.  

V. Complementing Non-Auto Modes

State of technology

CAV technologies can affect urban traffic in a variety of ways, through improvements in traffic flow, shifts in routing, and changes to parking strategies. The arrival of autonomous vehicles in urban areas will introduce a qualitatively different set of issues, however. While the deployment of fully autonomous vehicles (AVs) is still many years away, cities that hope to ensure these vehicles will help to achieve their transportation objectives are already laying the policy and infrastructure groundwork for their arrival. Numerous cities have served as living labs for the testing of AVs, including Pittsburgh in partnership with Uber and Washington, DC as part of an arrangement with Ford.

Effects on energy use

The energy-related impacts of autonomous vehicles in urban environments will depend on how these vehicles are integrated into the broader transportation system. Autonomous vehicles may be more fuel-efficient due to connectivity and automation features, and perhaps their likelihood of electrification; but their impacts on energy use and the environment will be strongly determined by how much they drive and the types of transportation they displace.

The number of miles driven by AVs will depend on vehicle ownership models (shared fleets or personal vehicles) and usage patterns. AVs could divert trips from less energy-intensive modes, increasing transportation fuel use. The quality of public transit in the United States varies significantly from city to city in its reliability, frequency, and cost. AVs will give people flexibility and more control over their schedules by offering door-to-door service, making them attractive to busy urban residents. The experience of ride-hailing services provides a preview of possible effects: one study found that users of ride-hailing services in major U.S. cities reduced their net transit usage by 6% on average; bus ridership was most strongly affected. Absent policies to avoid this outcome, the diversion of trips from transit to

ride-hailing is likely only to increase with the cost reductions anticipated with the deployment of autonomous vehicles in TNC fleets.

Alternatively, AVs could enhance connections between different modes of travel to create more sustainable urban transportation systems. They could serve as first- and last-mile connectors and service gap fillers. AVs could make rail stations and bus stops more easily accessible, and transit more affordable, by eliminating the need to park and tie up a vehicle unused for the day. This can curb daily, long, single-occupant trips and perhaps reduce vehicle ownership. Affordable ride-hailing would provide under-resourced communities with connections to transit facilities, allowing them to access jobs and services more easily. Integration of payment mechanisms systems and trip planning tools to facilitate transfer between transit, rideshare, and other travel modes could increase the convenience and practicality of intermodal passenger travel. AVs could also be used by transit agencies to expand service at relatively low cost by providing on-demand, flexible-route services outside the high-density corridors well-served by rail and bus.38

Widespread adoption of shared AVs could permit a major reallocation of urban space. Most American urban environments are built to cater to personal vehicles. The average American city devotes on the order of 50-60% of downtown space to car-related services and infrastructure;39 LA County dedicates 14% of its total land mass to parking facilities alone.40 Displacement of a large fleet of privately owned, infrequently used vehicles by a smaller, shared fleet of vehicles in constant use would release some of

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this valuable land for additional bicycle and pedestrian infrastructure, more affordable housing around key transit nodes, and generally denser, multi-use communities. Similarly, with more land for transit expansion comes the opportunity for AVs to support new transit ridership and transit investment. Yet by allowing travelers to use commute time productively, AVs could also make longer commutes acceptable and thus promote suburban sprawl.

Policy issues

Transit and infrastructure investment. Some commentators cite the advent of AVs as an argument against state and city investment in transit. But well-used public transit will remain the most efficient way, in terms of the use of both public space and energy, to move people along high-density routes. A robust transit system requires public commitment and resources, including ongoing infrastructure investment. To create transportation systems that achieve their goals, cities will need to anticipate opportunities to reallocate urban space due to any shifts in car ownership and usage patterns in order. A suitable regulatory environment and working relationship with TNCs would be needed to develop public-private partnerships to expand public transit services.

Integration of modes. Effective coordination of travel modes and services will depend upon standardization of V2V and V2I (vehicle-to-infrastructure) communications, trip planning tools and fare payment systems that extend across providers, and other actions to maximize the efficiency of modal transfers. Creation of a platform and standards for sharable transportation data will help to advance public-private collaboration on mobility.

Ownership and use of AVs. Realizing the energy and sustainability benefits of AVs in urban areas depends upon their being primarily owned by fleets and used for shared rides. Policies that have been proposed to achieve these outcomes include prohibiting individual ownership of AVs in cities and adopting a road pricing program that internalizes the costs that vehicles impose on the city. CAV technologies could facilitate the implementation of well-designed and equitable fee structure for roadway usage and environmental impacts. Having autonomous vehicles pay their share of costs along with other automobiles could avoid an artificially low price for trips in these vehicles, which will help to protect transit and generate revenue that could be applied to support it. Indeed, an extensive transit network is essential to avoiding adverse impacts on low-income communities from road pricing.

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42 McDowell.
46 Dooley.
VI. Conclusion

CAV technologies are developing rapidly and are steadily making their way into new vehicles. There are clear needs for protocols to ensure safety and data security, and policymakers and stakeholders are in the process of developing such policies. But the energy and, more broadly, sustainability implications of these new technologies and the changes to mobility options and behaviors that they will enable are enormous, and they call for proactive policymaking as well.

The examples in this paper illustrate diverse areas in which policy has a role in determining CAVs’ energy outcomes. They also suggest that, while many of these outcomes will be determined over the decades to come, is it possible and in fact essential to start now to put in place the principles and frameworks that will ensure that these vehicles will help to achieve environmental goals along with the other benefits they can deliver. Rather than view the energy effects of CAV adoption as an unknown to be accommodated as it emerges, stakeholders in the future of transportation and energy need to guide these new technologies to help create the transportation systems we want.
Application Pathways for Connected & Automated Commercial Vehicles

Aravind Kailas, PhD
May 6, 2019

Leading global manufacturer of trucks, buses, construction EQ, and marine and industrial engines
Connectivity and automated driving will allow for cleaner and safer megacities to grow and prosper

Automation will redefine the commercial transport solutions that most of us rely on every day

The first autonomous commercial solution  Autonomous bus trial in Singapore  Bleeding-edge innovations

Volvo Group will introduce automated applications gradually over time
V2X technologies are enablers for increasing transportation safety and efficiency

- **Nov 2015**: First-ever testing of V2I apps on public roads in Farmington Hills, MI
- **Mar 2016**: First-ever FHWA V2I demonstration in Fowlerville, MI
- **Oct 2016**: Testing on public roads and live work zones in MI
- **Jan 2017**: First-ever V2I demonstration in Washington, DC
- **Sep 2017**: Seminal efforts for standardization and harmonization of V2I across US - in MI, TX, AZ, CA, …

Created a regional partnership to assess air quality improvements near the ports using V2X technologies
Introduction to Ricardo Strategic Consulting

Ricardo has a deep history in the vehicle sector and is well positioned to provide value with a global footprint

- A global, multi-industry, multi-discipline consultancy and niche manufacturer of high-performance products
- The objective throughout our history has been to maximize efficiency and eliminate waste in everything we do

Today

Ricardo is a global strategic, technical and environmental consultancy and specialist niche manufacturer of high performance products. We also provide independent assurance services in the rail sector.
RSC is providing strategic insight, technology roadmaps and assessing market opportunities for clients in advanced mobility

Example Activity Areas

| Connectivity | • The connectivity revolution  
| Vehiches and the Internet of Things | • Offboard vehicle technology roadmap  
| | • OTA / Telematics revenue streams  
| | • Role of 5G and DSRC  
| | |  
| Dominance of ADAS Sensor systems  
| Complexity and cost management | • Production ADAS benchmarking  
| | • Technology and cost roadmaps  
| | • Evolution of electronic architecture  
| | • Future software and hardware value  
| | |  
| Cybersecurity | • Cybersecurity and the Vehicle  
| | • Knowledge development courses  
| | • Automotive resilience strategies  
| | • Customized cybersecurity support  
| | |  
| Rise of Mobility as a Service | • Use cases for urban mobility vehicles  
| | • Market sizing & deployment rates  
| | • Economic impact for consumers  
| | • Impacts to traditional value chain  
| | |  
| Pervasiveness of Personal Mobility Vehicles  
| Connected, electric 2 and 3 wheelers | • Growth in use cases for 2Ws  
| | • Two wheeler market growth  
| | • Connectivity as an enabler for growth  
| | • City mobility and 2W / 3W for hire  
| | |  
| Arrival of passenger, goods and surveillance drones | • Piloted drones instead of helicopters  
| | • Market opportunity sizing  
| | • Component supply chain  
| | • Autonomous / unmanned systems  

Industry Drivers
There are a number of drivers for deployment of ADAS and Autonomous technology for trucks

Industry Drivers for ADAS and Autonomous Driving

<table>
<thead>
<tr>
<th>American Transportation Research Institute states the following top 10 issues for US Truck fleets</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Electronic Logging Device Mandate</td>
</tr>
<tr>
<td>2. Hours-of-Service</td>
</tr>
<tr>
<td>3. Cumulative Impacts of Regulations</td>
</tr>
<tr>
<td>4. Truck Parking</td>
</tr>
<tr>
<td>5. Economy</td>
</tr>
<tr>
<td>6. Compliance, Safety, Accountability (CSA)</td>
</tr>
<tr>
<td>7. Driver Shortage</td>
</tr>
<tr>
<td>8. Driver Retention</td>
</tr>
<tr>
<td>9. Infrastructure/Congestion/Funding</td>
</tr>
<tr>
<td>10. Driver Distraction</td>
</tr>
</tbody>
</table>

Potential benefits from ADAS and Autonomous technology:

- Improve safety for all road users
- Operational cost benefits through fuel savings
- Improve operational efficiency and reduce costs
- Increase of hours of service by keeping vehicle mobile while driver takes mandated breaks
- Assist with parking
- Meet electronic logging requirements
- Minimize driver distraction
- Reduce stress of driving and improve driver retention

Significant interest from fleets in cost effective ADAS and Autonomous Systems
Vocation-specific benefits of AV technologies is substantial; companies should take a broad view of the opportunities.

Autonomous Vehicle Technology Benefits

<table>
<thead>
<tr>
<th>Benefit</th>
<th>Technology Example</th>
<th>Line haul</th>
<th>Last mile delivery</th>
<th>Short hauls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety / Mandate</td>
<td>AEB, ESC, V2V</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Collision Avoidance</td>
<td>FCW, RCW</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Convenience</td>
<td>Parking, HWY lane keeping, traffic jam assist</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Fuel economy, Operational efficiency</td>
<td>Platooning, advanced routing, depot parking, yard shunting</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Driverless</td>
<td>Fully autonomous driving</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
</tbody>
</table>

Key

- ● Substantial benefit
- ○ Minimal benefit

Certain vocations such as line haul and some short haul will drive semi and fully autonomous technology development and deployment.

Operating costs

Line haul operations have 6X the OPEX cost of last mile delivery primarily due to higher mileage, except for driver costs (2X).

Source: Ricardo analysis of average cost within US truck industry scaled by truck mileage where appropriate.
Semi-autonomous line haul trucks receive significant OPEX benefit from platooning: fuel economy and driver productivity

**Example Economic Opportunity for Line Haul Trucks**

<table>
<thead>
<tr>
<th>Category</th>
<th>Baseline</th>
<th>Repair</th>
<th>Fuel</th>
<th>Insurance</th>
<th>Platoon</th>
<th>Semi-AV OPEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Operating Cost</td>
<td>$165,000</td>
<td>$3,000</td>
<td>$6,500</td>
<td>$3,000</td>
<td>$60,000</td>
<td>$92,500</td>
</tr>
</tbody>
</table>

Platooning enhances driver productivity: Vehicle operates while driver is resting or other tasks (~L4)

Assumptions:
- Based on Line Haul scenario.
- RESULTS WILL VARY WITH ASSUMPTIONS ON VEHICLE OPERATION.
- SOURCE: DOT ‘BEYOND TRAFFIC’ REPORT

US freight volume expected to grow from 13.2 B Tons in 2012 to 18.8 B Tons in 2040 (+43%)

**Selected Observations on Connected Autonomous Technologies**

Last mile package delivery scenario shows limited financial benefit for autonomous driving unless driver costs reduce

**Example Economic Opportunity for Last Mile Delivery**

<table>
<thead>
<tr>
<th>Category</th>
<th>Baseline</th>
<th>Repair</th>
<th>Fuel</th>
<th>Insurance</th>
<th>ADAS</th>
<th>Autonomous</th>
<th>final OPEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Operating Cost</td>
<td>$53,000</td>
<td>$500</td>
<td>$0</td>
<td>$500</td>
<td>$1,750</td>
<td>$50,250</td>
<td>$50,250</td>
</tr>
</tbody>
</table>

Autonomous operation (L4) allows driver to perform other tasks while vehicle is operating. Further savings possible if driver is not needed for package delivery

Assumptions:
- Based on last mile, package delivery.
- RESULTS WILL VARY WITH ASSUMPTIONS ON VEHICLE OPERATION.
A scenario of potential benefits for ADAS and Autonomous Technology can be used to assess economics of adoption

Scenario to assess economic benefit of ADAS and Autonomy

<table>
<thead>
<tr>
<th>Operating Cost</th>
<th>Line Haul</th>
<th>Last Mile Delivery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repair</td>
<td>• ADAS can prevent accidental damage</td>
<td>• ADAS can prevent accidental damage</td>
</tr>
<tr>
<td></td>
<td>• Fully autonomous should have no accidents</td>
<td>• Fully autonomous should have no accidents</td>
</tr>
<tr>
<td>Maintenance</td>
<td>• Assumed not impacted by ADAS or Autonomy</td>
<td>• Assumed not impacted by ADAS or Autonomy</td>
</tr>
<tr>
<td></td>
<td>• Would benefit from connected services</td>
<td>• Would benefit from connected services</td>
</tr>
<tr>
<td>Insurance</td>
<td>• Reduction due to lower accidental damage</td>
<td>• Reduction due to lower accidental damage</td>
</tr>
<tr>
<td></td>
<td>• Anti-theft is additional benefit from connected services</td>
<td>• Anti-theft is additional benefit from connected services</td>
</tr>
<tr>
<td>Fuel</td>
<td>• Fuel efficiency benefits from platooning</td>
<td>• Limited fuel economy benefit except from improved low speed crawl</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Connected services could improve efficiency</td>
</tr>
<tr>
<td>Driver</td>
<td>• Operational efficiency benefit if vehicle moves while driver rests</td>
<td>• Last mile delivery may always need a driver to deliver the package from the vehicle. Hence limited benefit from full automotive without additional handling infrastructure</td>
</tr>
</tbody>
</table>

Scenario only includes ADAS and Autonomous Technology.

*Operational benefits from connected services were not included; and are additive to the above benefits*

Selected Observations on Connected Autonomous Technologies

Last mile drone delivery is growing, and further demonstrates benefits of connectivity opportunities

**Example: Drone Grocery Last Mile Delivery**

Kroger: objectives of unmanned pilot delivery in Scottsdale, Arizona

- Place an order on mobile app or website; order same-day or next-day
- 7 days/week $5.95 flat fee; no minimum order
- "redefine the grocery experience by creating an ecosystem that offers our customers anything, anytime and anywhere" – Kroger
- AZ program will end in May after ~2000 grocery deliveries; now expanding to Houston
  - customers who participated in the Scottsdale pilot will switch over to an existing grocery-delivery service provided by Kroger.

4 percent of Americans shop for groceries online on a weekly basis; Gallup researchers concluded that this highlights the industry's potential for large-scale change.
**Connected Truck**

**Connected truck market currently valued at $10bn; expected to grow to $245bn by 2025**

**Connected Services Market Value (V2V, V2I)**

<table>
<thead>
<tr>
<th>2017</th>
<th>2025</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10bn</td>
<td>$245bn</td>
</tr>
</tbody>
</table>

- **10-15% Increase In Productivity**
- **10-15% Reduction in Overtime**
- **20-25% Reduction In Fuel Expenses**
- **5-10% Reduction In Total Miles**
- **20-30 Minutes of Daily Driver Labor Savings**
- **20-30% Reduction in Vehicle Idle Time**

**Annual OPEX savings: $6k to $9k (MD Delivery truck) $20k to $30k (Long haul truck)**

*Source: Frost and Sullivan’s Global Connected Truck Study*

**Commercial Vehicle Market Outlook**

Value of connected services needs to be understood for targeted truck vocations to identify the most relevant features

<table>
<thead>
<tr>
<th>Cost Reduction</th>
<th>Time Savings</th>
<th>Safety &amp; Security</th>
<th>Convenience</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced scheduling (25% of EU truck trips are empty vehicles)</td>
<td>Advanced routing (avoid road work, congestion, etc.)</td>
<td>Anti-theft (Vehicle &amp; Cargo monitoring)</td>
<td>Over-the-air software updates</td>
<td>Road law monitoring and enforcement</td>
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<tr>
<td>On-demand delivery services</td>
<td>Rapid deployment</td>
<td>Driver condition monitoring</td>
<td>Telematics diagnostics</td>
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<tr>
<td>Fleet management solutions</td>
<td>Traffic Information</td>
<td>Breakdown / Emergency call service</td>
<td>Automatic completion of mandated forms</td>
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<tr>
<td>Predictive maintenance and scheduling</td>
<td>Parking spot finder</td>
<td>Improved road maintenance</td>
<td>Automation of fleet specific requirements (delivery notification)</td>
<td></td>
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<tr>
<td>Driving style monitoring and recommendations</td>
<td>Geo-fencing of operations in sensitive areas</td>
<td>Music/video streaming</td>
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<tr>
<td>Usage based insurance, tolls, and taxes</td>
<td>Inclement weather warning &amp; speed management</td>
<td>Wifi hotspot</td>
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<td>Vehicle Uptime Improvement</td>
<td>Road hazards</td>
<td>Concierge services</td>
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<tr>
<td>Enabling truck platooning</td>
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<tr>
<td>Intelligent Transportation (Eco-approach/ departure)</td>
<td></td>
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</tr>
</tbody>
</table>

**Potential Benefits for End-users (fleets)**

- **Revenue via direct monetization**
  - Upfront payment
  - Subscription
  - Usage based

**Potential Benefits for Technology Providers / OEMs**

- Warranty cost reduction
- Data driven R&D optimization
- OTA updates (reduced dealership costs)

*American Transportation Research Institute top 10 issues for US Truck fleets* (Number reference in table above correspond to numbers below)

- Electronic Logging Device Mandate
- Hours-of-Service
- Cumulative Impacts of Regulations
- Truck Parking
- Economy
- Compliance, Safety, Accountability (CSA)
- Driver Shortage
- Driver Retention
- Infrastructure/Congestion/Funding
- Driver Distraction

*Source: Ricardo analysis*

© Ricardo plc 2019

May 6, 2019

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## Technology | Ricardo View
---|---
Connectivity | • Will have **significant impact** on commercial vehicle operations in **next few years**  
• Could help **redefine business models** in select vocations  
• Will likely enable other **ADAS and Autonomous driving** features
ADAS (SAE level 1 and 2) | • May not have strongest business case, but **could reduce repairs/insurance and help with driver attraction/retention**.  
• Certain ADAS features likely to be **mandated** for safety  
• May need to be offered to be competitive in market
Semi-Autonomous (SAE level 3 and 4) | • **Strong business case for certain vocations**, will be adopted in these vocations as soon as available (e.g.: line haul).  
• Some vocations do NOT show as attractive a business case for semi-autonomous (e.g. last mile)  
• **Platooning likely to enter market in near future** driven by European and US interests
Fully-Autonomous (SAE Level 5) | • Excludes level 4 highway pilot / platooning / traffic jam assist where full autonomy is possible in certain situations  
• **Significant cost-benefit advantage in certain vocations** will continue to drive development  
• A fully autonomous, all time vehicle appears to be several years away

**Significant opportunity for connectivity across all vocations, and quick deployment of semi-autonomous in select vocations**

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### Thank You

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Mark S. Kuhn  
Vice President  
Ricardo Strategic Consulting  
Ricardo US Inc. – Detroit Technical Campus  
40000 Ricardo Drive  
Van Buren Township  
MI 48111, USA  
Mark.Kuhn@ricardo.com  
www.ricardo.com
Energy Impacts of CAVs – Goods Movement

Mike Roeth, Executive Director, NACFE
ACEEE May 6, 2019

NACFE

- Unbiased, non-profit
- Mission to double freight efficiency
- Scaling Available Technologies
- Guiding Future Change
- Run on Less Demonstrations

www.NACFE.org
N.A. Fuel Situation

Trucking’s Actions

- Lowering fuel cost
  - 2017 Cost per mile up 9.5%, while cost at the pump was up 15%.
- Planning for future fuel costs
- Government Regulations – US Federal GHG, State & Local
- Corporate Sustainability

Wave Of Changes Coming
Regional Haul

More Regional Haul: An Opportunity for Trucking?
• Drop in Length of Haul
• Warehousing
• Trends
• An Opportunity
  • Drivers
  • Alternative Fuels
  • Others?

Report published April 22\textsuperscript{nd}.

Annual Fleet Fuel Study

2018 Study Released August 28, 2018 – Report and Dataset free to download at www.nacfe.org
Equipment Adoption

Platooning Capable

Average NACFE Fleets "Unit" Adoption

Time

Two-Truck Platooning

October 2016
CONFIDENCE REPORT:
Two-Truck Platooning

www.nacfe.org/technology/two-truck-platooning/
## Benefits & Costs

<table>
<thead>
<tr>
<th>Safety Techs</th>
<th>Platooning</th>
<th>Assisted Driving</th>
<th>Powered Trailer</th>
<th>Automated Driving</th>
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</thead>
<tbody>
<tr>
<td>Benefits</td>
<td>Less accidents &amp; Repairs</td>
<td>Fuel</td>
<td>Enhanced Performance</td>
<td>Lower labor More payload</td>
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<tr>
<td>Costs</td>
<td>Increasing upfront costs until vehicle redesigns with autonomous operation.</td>
<td>Maintenance increases with complexity and decreases with gentler operation.</td>
<td></td>
<td></td>
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</tbody>
</table>

### Automation with Benefits: Greener Goods Movement in a Connected, Autonomous World

ACEEE Forum on Connected and Automated Vehicles

Karl Simon,
Director, TCD, US EPA
May 06, 2019
Platooning
Eco-driving
Congestion mitigation
De-emphasized performance
Improved crash avoidance
Vehicle right-sizing
Higher highway speeds
Increased features
Travel cost reduction
New user groups
Changed mobility services
Infrastructure footprint*

% changes in energy consumption due to vehicle automation
Semi-truck photo: Toyota
Applications & Permit Fees
Truck Photo: Tesla

Thank You
Potential Energy Impacts of Automated Driving
an overview of our research results

Jean Chu, Ph.D.
Toyota Motors North America R&D

May 6th, 2019
ACEEE Forum on Connected and Automated Vehicles: Energy Impacts

What Will be the Impacts of AD?

5 years ago in July, at Automated Vehicle Symposium...

My colleague, Ken Laberteaux, predicted that,
without policy changes, in the US, Level 2+3 Automated Driving will likely:

• Increase highway speeds (mostly via reduced congestion and accidents)
• Increase automobile Vehicle Miles Travelled
• Increase commute distances (with roughly same commute time as today)
• Less likely (vs Level 4/5) to provide new vehicle ownership models and usage cases
What Will be the Impacts of AD?

The next day 5 years ago, on Jalopnik.com blog...

This Toyota Scientist Is Wrong About Urban Sprawl And Self-Driving Cars

“Ken Laberteaux is a senior principal scientist for Toyota North America, and he's convinced that self-driving cars will increase pollution, exacerbate urban sprawl, and ruin our families. I'm pretty sure there's something in there about killing kittens too, but I may have missed it in his haze of pessimistic, contrarian bull****.”

…and now, almost 5 years later, who was right????

We don’t know for sure.

But we are making progress
Q1: Which drivers would benefit most from low-complexity, Level 2 AD?

A1: The highway drivers, living in the distant suburbs\textsuperscript{2}

\textsuperscript{2}Method for Gauging Usage Opportunities for Partially Automated Vehicles with Application to Public Travel Survey Data Sets, Laberteaux, Hamza, Berger, Brown, Transportation Research Record, Volume 2625, 2017

Partial AD Availability Preliminary Results

Far more Atlanta drivers (at least 2.75X) will have use for AD Highway vs AD Traffic Jam (with heaviest users in exurbs)
Q2: Which regions would benefit most from higher-complexity, Level 4-5 AD, personally-owned vehicles?

A2: The distant suburbs³

³Preliminary results from a Toyota R&D collaboration with U-Washington Prof. Don MacKenzie’s Lab were presented at 2019 Transportation Research Board Annual Meeting (Paper No. 19-05259)

Change of demand after introducing Magic Carpets (approximating high-level automated vehicles) replacing the personal vehicle.

[Assumed same cost per mile as current personal vehicle, but half of the travel time cost. Housing cost remains unchanged.]

Housing demand shifts to the surrounding suburban zones in south and northeast, where people are likely to drive with long commute time.
So, if AD on personally-owned vehicles is likely to benefit long-distance commute and increase Vehicle Miles Travelled, can we at least expect AV to be more energy efficient or electrified?

**Table:**

<table>
<thead>
<tr>
<th>Autonomous Vehicle</th>
<th>Electric Vehicle</th>
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</tbody>
</table>

Q3: What could be the impact of power consumption in AD system on vehicle energy efficiency?

A3: Reduction in efficiency and driving range could be significant\(^4\)

---

Present-day power consumption of AD system (~2.5 kW) could shorten the electric driving range by 1/3 and increase fuel consumption by up to 32% compared to same vehicle model with no AD system.

We don’t have all the answers to the future, but what can we say now?

- While automated driving makes driving easier and more convenient, people are likely to live further and drive (or be driven) more
- AD system could have non-trivial impact on energy efficiency and electric driving range, which could be particularly unfavorable for short-range BEV

But still, there are much more we don’t know yet.
GM’s World View

GM is committed to a future of:

- **Zero Crashes**
- **Zero Emissions**
- **Zero Congestion**

*Autonomous vehicle technology will help unlock this future*
COMMUTERS WASTE A FULL WEEK OF THEIR LIVES IN TRAFFIC EACH YEAR

* Source: Auto Insurance Center

THE U.S. HAS 3 NON-RESIDENTIAL PARKING SPACES FOR EVERY CAR ON THE ROAD

* Source: NY Times, Eran Ben-Joseph
94% of all traffic accidents are caused by human error.

*Source: NHTSA, Fatal Accident Reporting System (FARS).

We believe all AVs should be EVs.
THE EV PLATFORM IS THE FOUNDATION FOR AUTONOMOUS VEHICLES

Leverages GM assets
Simpler integration of technologies
Optimal for urban environment

SUPPORTS OUR ZERO EMISSIONS FUTURE WORLD VIEW

POLICY CHALLENGES AND OPPORTUNITIES

• FUEL ECONOMY LABELING, FMVSS REQUIREMENTS, AND REGULATORY TREATMENT

• INFRASTRUCTURE
  • EV CHARGING
  • STREETScape
  • BUILDING CODES

• CITY REQUIREMENTS

• CONNECTIVITY

Today’s policies, regulations, and incentives contemplate personal retail use

Tomorrow’s policies should make room for new technologies in shared use
Shared Autonomous Electric Mobility: Opportunities & Challenges

T. Donna Chen, PE, PhD
Assistant Professor
Department of Engineering Systems & Environment
May 6, 2019

Why Shared Autonomous Electric Vehicles (SAEVs)?

- eliminates driver labor cost. Enables strategic relocation (avoiding spatial mismatch of demand & supply).
- high cost of automation technology incentivizes shared use.
- accelerates EV adoption to meet urban air quality & transport emissions goals.
- automated charging/fueling is easier to achieve with electric vehicles.
- fewer components lead to reduced maintenance (compared to internal combustion engine vehicles).
- alleviates “range anxiety.”
Shared Autonomous Electric Vehicle
Chen Research Group

Vehicle Automation

Vehicle Electrification

Use Case

EV-Grid Interaction

Shared AV

EV Range & Charging Infrastructure

Door-to-Door service (single occupant)¹,²
Door-to-Door service (with ridesharing)³
First/Last Mile Connection with Transit ⁴

Smart Charging Management⁵

SAEV Modeling Framework


Trip Generation

• Use local travel demand model data to generate trips to simulate origin-destination travel demand

Charging Station Generation

• Charging station site selection to ensure sufficient infrastructure coverage

SAEV Fleet Generation

• Determine the necessary fleet size to serve travel demand

Operation

• Continuous daily operation based on the station and fleet configuration
**SAEV Use Case: Door-to-Door Service**

Case studies in Austin, Texas

**Door-to-Door SAEV Service: Single Occupant**

Fleet Size by Vehicle & Charging Infrastructure

<table>
<thead>
<tr>
<th></th>
<th>SAV</th>
<th>SAEV</th>
<th>SAEV Fast Charge</th>
<th>LR SAEV</th>
<th>LR SAEV Fast Charge</th>
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<td>21693</td>
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</tbody>
</table>

- **Fast charging** infrastructure & **longer EV range** reduces required fleet size.
- Each SAEV can **serve 11 to 21 trips per day**, equivalent to **replacing 3.7 to 6.8 privately owned vehicles**. This will significantly reduce parking requirements.
- “**Empty**” VMT constitutes **7 to 14%** of all miles traveled, with short-range EVs incurring more zero-occupant miles due to more trips for recharging.
Door-to-Door SAEV Service: **Single Occupant** Operational Cost Per Occupied-Mile Traveled

- **SR SAEVs with Level II charging** are cheapest to operate on a per-mile basis, even if this configuration incurs highest % “empty” VMT (increases congestion) and require biggest fleet (requires more land for charging spots).

SAEV Door-to-Door Service with **Dynamic Ridesharing**

- **“Empty” VMT** comprises 9-16% of total VMT for SAEV with ridesharing.
- Assuming all travelers are willing to participate in ridesharing, about 35% of all VMT include at least two passengers.
- One SAEV with dynamic ridesharing can replace 8 to 13 privately owned vehicles.
SAEV Door-to-Door Service w/ Dynamic Ridesharing

• Though the total % of trips served exceeds 96% in all scenarios, the likelihood of matching a vehicle with a passenger varies by time of day. During peak hours, matching rates can be as low as 85%.

SAEV Use Case: First/Last Mile Connection

Case study in Seattle, Washington
SAEVs for First/Last Mile Connection

- SAEVs can increase the catchment areas for transit service & decrease the demand for scarce parking spots at Park & Rides.

Case study at Tukwila Light Rail Station in Seattle, Washington using
- 2016 survey of rider origin-destinations
- Hourly boarding & alighting data
- Ridership catchment area based on home addresses on Park & Ride license plates.

- Enabling ridesharing in SAEVs for first/last mile mobility reduce system-wide VMT by 37% (compared to single occupancy).
- If all travelers participate in ridesharing, 40-45% of all VMT include at least two passengers, and ridematch rate is higher during AM & PM peaks.
- “Empty” VMT remains around 20% with ridesharing in all vehicle & charging infrastructure scenarios.
- One SAEV with dynamic ridesharing can replace 20 to 34 “park & ride” vehicles.
Charging “as needed” minimizes SAEV “empty” travel distance for charging, but exhibits peak charging periods which coincide with existing peak hours of electricity use.
SAEV-Grid Interaction

SAEV Smart Charging under TOU Pricing

With increased battery capacity, **LR vehicles** exhibit superior ability to avoid charging on-peak. Compared to unmanaged charging, electricity costs can reduce 10% (SR SAEVs) to 34% (LR SAEVs).

**SAEVs: Key Takeaways**

- When including ridesharing, SAEVs are more efficient at serving first/last mile connection trips than door-to-door trips (higher average occupancy, better ridematch rates during peak hours).
  - How can we encourage SAEVs as part of a multimodal trip rather than a new replacement mode?
- “Empty” VMT alone is not indicative of service efficiency. Use cases with higher “empty” VMT can mean higher average vehicle occupancy across all VMT.
  - Don’t let the bad publicity of the empty autonomous car get in the way of the real focus: higher average occupancy.
- Charging station capacity can be reduced with longer range vehicles, fast charging infrastructure, and higher ridematch rates.
  - But shorter range vehicles & Level II charging infrastructure are cheaper for the fleet operator to acquire & implement. Bringing down battery costs is critical in enabling efficient SAEV fleets.
- Battery capacity plays an essential role in SAEV-grid interactions. Larger batteries enable SAEVs to act simultaneously as energy user & storage.
  - In addition to lowering battery costs, tiered or dynamic electricity pricing structures will incentivize energy-efficient SAEV operations.
Thank you for your time!

T. Donna Chen    tdchen@virginia.edu
WHAT WILL AUTONOMOUS VEHICLES MEAN?

- Possible rapid changes in transportation sector in near future
- Megatrends and technology may lead to new paradigms
- What is the impact on energy?

LIGHT-DUTY VEHICLE ENERGY CONSUMPTION

- How much energy are vehicles using / how much fuel are vehicles consuming?

\[
\text{Energy} = \text{Demand} \times \text{Efficiency} = \frac{VMT}{MPG}
\]

DOE SMART MOBILITY

- Multi-lab consortium to answer research questions about new mobility paradigms
- Informs factors and scenarios for national-scale energy analysis
ESTIMATED BOUNDS OF FUEL USE BY CAVS

- Partial automation: (~SAE level 2) ± 10–15%
- Full automation: (~SAE level 4-5) -60% / +200%
- Ride-sharing: Reduction of up to 12%


WHAT FACTORS WILL IMPACT FUEL USE?

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<th>Demand</th>
<th>Efficiency</th>
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<tr>
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<td>11</td>
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<tr>
<td>12</td>
<td>24</td>
</tr>
</tbody>
</table>

- Off-board computation & data centers
- Electronics power draw
- Aerodynamic drag (sensors)
- Engine downsizing
- Vehicle rightsizing
- Vehicle lightweighting
- Vehicle upsizing (mobile lounges)
ELECTRONICS POWER DRAW

- Auxiliary load for CAVs electronics can be substantial, lowering fuel economy

Source: Gawron et al., 2018. https://pubs.acs.org/doi/10.1021/acs.est.7b04576


ELECTRONICS DESIGN ARCHITECTURES

- Power can be minimized with specialized chips; latency major concern

Source: Lin et al., 2018. https://doi.org/10.1145/3173162.3173191
PERFORMANCE VS. POWER

- Tesla presented custom-designed chip for self-driving vehicles
- Notable increase in visual computational capabilities, and modest increase in power draw

OFF-BOARD ENERGY REQUIREMENTS

- Not all computing will be on vehicle
  - “System critical” operations will

- Key off-board computational needs:
  - Dispatching & real-time routing
  - Data storage & recording
  - AI training

- Need to be cognizant of using best practices to minimize energy consumption by computer servers

Source: Tesla Autonomy Day. https://www.youtube.com/watch?v=UcpOTTmvOE&list=5482
ACKNOWLEDGEMENTS

- This report and the work described were sponsored by the U.S. Department of Energy (DOE) Vehicle Technologies Office (VTO) under the Systems and Modeling for Accelerated Research in Transportation (SMART) Mobility Laboratory Consortium, an initiative of the Energy Efficient Mobility Systems (EEMS) Program. The authors acknowledge Eric Rask of Argonne National Laboratory for leading the Connected and Automated Vehicle Pillar of the SMART Mobility Laboratory Consortium. The following DOE Office of Energy Efficiency and Renewable Energy (EERE) managers played important roles in establishing the project concept, advancing implementation, and providing ongoing guidance: David Anderson, Erin Boyd, Heather Croteau, Prasad Gupte, Rachael Nealer, and Jacob Ward.

Contact: gohlke@anl.gov
Most cities are not big cities

Car-free Households

<table>
<thead>
<tr>
<th>City</th>
<th>Population rank</th>
<th>2007</th>
<th>2012</th>
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<td>6.1</td>
<td>-0.9</td>
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<tr>
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<td>10</td>
<td>5.4</td>
<td>5.8</td>
<td>+0.4</td>
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</tbody>
</table>
CAVs and Sustainability

How to achieve sustainability?

• Car-free or car-lite households
  • Land use
  • Fewer vehicle trips
  • More NMT, transit trips
• People-oriented streets/cities
• Prioritizing Transit

How to fail at sustainability?

• VMT
  • Zombie Trips
• Auto trips
  • From sustainable modes
• Sprawl
• Auto-oriented streets/cities
What tools do (mid-sized) cities have?

- Depends on the state
- Zoning
- Curbside management
- Street layout
- City plans
- AV testing
- Transit Corridors
- Partnerships
- Lobbying

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WHAT WILL AUTONOMOUS VEHICLES MEAN?

- Possible rapid changes in transportation sector in near future
- Megatrends and technology may lead to new paradigms
- What is the impact on energy?


LIGHT-DUTY VEHICLE ENERGY CONSUMPTION

- How much energy are vehicles using / how much fuel are vehicles consuming?

\[
\text{Energy} = \text{Demand} \times \text{Efficiency} = \frac{VMT}{MPG}
\]
DOE SMART MOBILITY

- Multi-lab consortium to answer research questions about new mobility paradigms
- Informs factors and scenarios for national-scale energy analysis

ESTIMATED BOUNDS OF FUEL USE BY CAVS

- Partial automation: (~SAE level 2) ± 10–15%
- Full automation: (~SAE level 4-5) -60% / +200%
- Ride-sharing: Reduction of up to 12%

## WHAT FACTORS WILL IMPACT FUEL USE?

<table>
<thead>
<tr>
<th>Personal mobility</th>
<th>Off-board computation &amp; data centers</th>
<th>New</th>
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</thead>
<tbody>
<tr>
<td>1  Shifting travel patterns - sprawl</td>
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<td>2  Shifting travel patterns - urbanization</td>
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<td>3  Additional travel - underserved</td>
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<td>4  Additional travel - leisure travel</td>
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<td>5  Mode shift to highway</td>
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<td>6  Re-routing (eco-routing)</td>
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<td>7  Ridesharing</td>
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<td>8  Empty VMT (deadhead)</td>
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<td>9  Additional fueling trips</td>
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<td>10 Efficient parking</td>
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<td>11 Change in shopping trips</td>
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<td>12 Commercially sponsored trips</td>
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<td>13 Changes in congestion</td>
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<td>14 Faster travel</td>
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<td>15 Drive smoothing</td>
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<td>16 Platooning</td>
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<td>17 V2X connectivity</td>
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<tr>
<td>18 Off-board computation &amp; data centers</td>
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<td>19 Electronics power draw</td>
<td>New</td>
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<td>20 Aerodynamic drag (sensors)</td>
<td>New</td>
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<td>21 Engine downsizing</td>
<td>New</td>
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<td>22 Vehicle rightsizing</td>
<td>New</td>
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<td>23 Vehicle lightweighting</td>
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<tr>
<td>24 Vehicle upsizing (mobile lounges)</td>
<td>New</td>
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</tbody>
</table>

### ELECTRONICS POWER DRAW

- Auxiliary load for CAVs electronics can be substantial, lowering fuel economy

Source: Gawron et al., 2018. [https://pubs.acs.org/doi/10.1021/acs.est.7b04576](https://pubs.acs.org/doi/10.1021/acs.est.7b04576)

ELECTRONICS DESIGN ARCHITECTURES

- Power can be minimized with specialized chips; latency major concern

Source: Lin et al., 2018. https://doi.org/10.1145/3173162.3173191

PERFORMANCE VS. POWER

- Tesla presented custom-designed chip for self-driving vehicles
- Notable increase in visual computational capabilities, and modest increase in power draw

Source: Tesla Autonomy Day. https://www.youtube.com/watch?v=Ucp0TTmvqOE&t=5482
OFF-BOARD ENERGY REQUIREMENTS

- Not all computing will be on vehicle
  - “System critical” operations will

- Key off-board computational needs:
  - Dispatching & real-time routing
  - Data storage & recording
  - AI training

- Need to be cognizant of using best practices to minimize energy consumption by computer servers

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Contact: gohlke@anl.gov