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Energy saving potentials of connected and automated vehicles

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ABSTRACT

Connected and automated vehicles (CAV) are marketed for their increased safety, driving comfort, and time saving potential. With much easier access to information, increased processing power, and precision control, they also offer unprecedented opportunities for energy efficient driving. This paper is an attempt to highlight the energy saving potential of connected and automated vehicles based on first principles of motion, optimal control theory, and a review of the vast but scattered eco-driving literature. We explain that connectivity to other vehicles and infrastructure allows better anticipation of upcoming events, such as hills, curves, slow traffic, state of traffic signals, and movement of neighboring vehicles. Automation allows vehicles to adjust their motion more precisely in anticipation of upcoming events, and save energy. Opportunities for cooperative driving could further increase energy efficiency of a group of vehicles by allowing them to move in a coordinated manner. Energy efficient motion of connected and automated vehicles could have a harmonizing effect on mixed traffic, leading to additional energy savings for neighboring vehicles.

1. Introduction

The shift that we are witnessing toward vehicle connectivity and autonomy is going to be perhaps, the most disruptive since the early days of automobiles and could revolutionize movement of people and goods. According to IHS Automotive, the number of connected cars sold globally will grow more to 152 million across the globe by 2020, a six fold increase with respect to 2015 (McCarthy, 2015). Another estimate puts the number of connected vehicles at 250 million vehicles by 2020 (Gartner, 2015), a fourth of the billion cars that are in service today. In 2016 the US Department of Transportation issued a notice of proposed rule making, that if implemented would require Vehicle-to-Vehicle (V2V) connectivity on all new light-duty vehicles and is intended to reduce the number of car accidents (NHTSA, 2016b). Similar provisions and guidelines are envisioned for Vehicle-to-Infrastructure (V2I) communication (FHWA, 2015). With implementation of such mandates the number of connected cars with access to information and data will rapidly increase. On a different front, major auto manufacturers, technology firms, and startup companies have started a race toward building fully automated cars. Many automated functions such as adaptive cruise control and lane keeping assist are already available on several production vehicles. It is expected that first fully automated vehicles be available for sale before 2020 (Center for Sustainable Systems, 2016; Alexander-Kearns et al., 2016). A projection is that 20–40% of vehicle sales be automated by 2030 and full penetration could happen in several stages over the next few decades (Litman, 2017).

This level of connectivity and autonomy will transform transportation of people and goods in several dimensions with important societal and economical impacts: improved safety, increased comfort, time saving potential, and more efficient road utilization are

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Table 1

Potential Impact of CAVs on (a) energy intensity or user intensity according to Brown et al. (2014) (b) operational energy use by year 2050 according to Wadud et al. (2016).

Contributing factors	Brown et al. (2014)	Wadud et al. (2016)
Platooning	(−)10 % EI[a]	(−) 2–10 %
Eco-driving	(−)15–40 % EI	(−) 20 %
Eco-routing	(−) 5 % EI	NA
Congestion mitigation	NA	(−)2–4%
De-emphasized performance	NA	(−) 5–23 %
Vehicle light-weighting	(−) 50 % EI	(−) 5–23 %
Vehicle right-sizing	(−) 12[d] % UI[b]	(−) 20–45 %
Changed mobility services	NA	(−) 0–20 %
Infrastructure footprint	NA	(−) 2–5%
Reduced parking search	(−) 4 % UI	NA
Enabling electrification	(−) 75 % FI[c]	NA
Higher highway speeds	(+) 30 %	(+) 5–25 %
Increased features	NA	(+) 0–10 %
Travel cost reduction	(+) 50 % UI	(+) 5–60 %
New user groups	(+) 40 % UI	(+) 2–10 %

[a] EI: Energy Intensity.
[b] UI: User Intensity.
[c] FI: Fuel Intensity.
[d] Higher occupancy facilitated by IT and automated carpooling.

among the most widely discussed positive impacts of CAVs. Fully automated vehicles could improve mobility of young, elderly, and people with disability who are unable to drive today. Ride sharing and on-demand mobility services could gain more popularity due to reduced labor cost, influencing also urban planning and land use.

Energy use has not been the core consideration in development of connected and automated vehicles, but it could be impacted significantly. The impact could be positive or negative according to Brown et al. (2014), Wadud et al. (2016) which is summarized in Table 1. A careful scenario analysis in Wadud et al. (2016) shows vehicle automation could reduce energy use and green house gas emissions in half in an optimistic scenario or double them in a “dystopian nightmare”, depending on the effects that come to dominate. Increased opportunities for eco-driving and platooning, traffic harmonization, vehicle light-weighting enabled by lower crash risk, vehicle right-sizing for number of travelers, de-emphasized vehicle performance, car-sharing and on-demand mobility, and reduced infrastructure footprint of automated vehicles all contribute to improved energy utilization according to Wadud et al. (2016). But according to the same study, the increase in vehicle miles traveled due to lower travel costs, addition of new user groups (young, elderly, disabled), higher highway speeds, and increased vehicle features can also dramatically increase the energy footprint of vehicle automation. The outcomes depend on which scenarios prevail and proactive policy making is essential to steer the technology toward energy efficiency as also emphasized in Wadud et al. (2016), Simon et al. (2015), Alexander-Kearns et al. (2016). The authors of Greenblatt and Shaheen (2015) speculate that the aggregate energy and environmental impact of automated and on-demand mobility could be positive; but acknowledge a big shift from historical trends that needs to be carefully watched by policy makers and planners.

This paper takes a more in-depth look at increased opportunities for energy efficient driving with connected and automated vehicles, disregarding second order effects of connectivity and automation, such as increased vehicle miles traveled or reduced vehicle weight. By connected we are referring to vehicles that use communication technologies such as DSRC, cellular, or even Wi-Fi for vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-cloud (V2C) communication. The U.S. Department of Transportation’s National Highway Traffic Safety Administration (NHTSA) defines fully automated vehicles as those in which operation of the vehicle occurs without direct driver input to control the steering, acceleration, and braking and are designed so that the driver is not expected to constantly monitor the roadway while operating in self-driving mode (USDOT, 2013). In categorizing partial automation, NHTSA’s federal automated vehicles policy (NHTSA, 2016a) adopts that of Society of Automative Engineers (SAE) definitions for levels of vehicle automation. Automation levels range from no automation with full driver control (Level 0) to full automation with no driver control (Level 5). Many of the benefits discussed in this paper are realizable with partial level 2 or 3 automation as they mostly rely on automated speed and steering control which can be overseen and overridden by a human driver.

Because CAVs are capable of sensing more accurately, processing more information, and can be more tightly controlled, they benefit more from information offered by connectivity and road preview. With higher penetration rate of CAVs, opportunities increase for vehicle to vehicle communication and cooperative control; which can lead to additional energy efficiency gains. Despite these prospects, connected and automated vehicle research and development have been mostly on software, sensing, and safety and there are limited results on energy efficiency potentials.

Over the past decade, various research groups have shown the positive influence of telematics, road preview, and connectivity on energy efficiency of conventional and hybrid vehicles through simulation and experimental investigations. For instance, in Manzie et al. (2007) it is shown that as little as 7 s traffic look-ahead capability could have the same energy efficiency benefit as hybridization. Due to the complex nature of the problem (different vehicle configurations, variability of scenarios, and sensitivity to choice of algorithms) the reported values for energy efficiency benefits are scattered and a concerted effort is needed to summarize