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Help or hindrance? The travel, energy and carbon impacts of highly automated vehicles

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ABSTRACT

Experts predict that new automobiles will be capable of driving themselves under limited conditions within 5–10 years, and under most conditions within 10–20 years. Automation may affect road vehicle energy consumption and greenhouse gas (GHG) emissions in a host of ways, positive and negative, by causing changes in travel demand, vehicle design, vehicle operating profiles, and choices of fuels. In this paper, we identify specific mechanisms through which automation may affect travel and energy demand and resulting GHG emissions and bring them together using a coherent energy decomposition framework. We review the literature for estimates of the energy impacts of each mechanism and, where the literature is lacking, develop our own estimates using engineering and economic analysis. We consider how widely applicable each mechanism is, and quantify the potential impact of each mechanism on a common basis: the percentage change it is expected to cause in total GHG emissions from light-duty or heavy-duty vehicles in the U.S. Our primary focus is travel related energy consumption and emissions, since potential lifecycle impacts are generally smaller in magnitude. We explore the net effects of automation on emissions through several illustrative scenarios, finding that automation might plausibly reduce road transport GHG emissions and energy use by nearly half – or nearly double them – depending on which effects come to dominate. We also find that many potential energy-reduction benefits may be realized through partial automation, while the major energy/emission downside risks appear more likely at full automation. We close by presenting some implications for policymakers and identifying priority areas for further research.

1. Introduction

Automated vehicles are defined as those in which at least some of the safety critical control functions (e.g. steering, throttle, or braking) occur without direct driver input (NHTSA, 2013). While there has always been substantial interest and continuous innovations in vehicle automation through various advanced driving assistance (ADA) technologies, vehicle longitudinal and lateral control systems, and navigation systems, Google's demonstration of a fully automated, autonomous

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vehicle in 2012 appears to herald a new era of automation. Most automobile manufacturers are already marketing vehicles with some automation features, and working to develop more highly automated and self-driving vehicles. A recent survey of self-identified experts in vehicle automation found a median estimate of 2019 (interquartile range: 2018–2020) as the initial date at which vehicles would be capable of driving themselves on freeways, with drivers available to take over as required. The same group predicted that vehicles would be capable of driving themselves on urban and rural surface roads and highways by 2025 (interquartile range: 2024–2030), and doing so in a failsafe manner (without a human driver backup) by 2030 (interquartile range: 2027–2035) (Underwood, 2014). Optimistic estimates predict that around 30% of the trucks in the UK could be automatically driven by 2022 (Wardrop, 2009), while up to 75% of the vehicles on road could be fully automated by 2040 (IEEE, 2012). Four cities in the UK will be hosting a fully automated vehicle demonstration, while the city of Gothenburg in Sweden is expected to pilot 100 fully automated vehicles in urban conditions in 2017. Regulators are attempting to keep pace, with four U.S. states (Nevada, California, Florida, and Michigan) plus the District of Columbia already legalizing the testing of driverless vehicles on their roads (CIS, 2015), and the UK government also allowing testing of automated vehicle recently. The U.S. National Highway Traffic Safety Administration (NHTSA, 2013) has also developed a taxonomy of levels of automation ranging from level 0 (no automation) to level 4 (full automation), to which we will refer frequently throughout this paper.

Automation *per se* is unlikely to significantly affect energy consumption, but is expected to facilitate myriad other changes in the road transportation system that may significantly alter energy consumption and GHG emissions. For example, automated vehicles may enable the adoption of energy-saving driving practices, and facilitate changes in the design of individual vehicles or the transportation system as a whole that enable reductions in energy intensity. Fully automated, self-driving cars can offer on-demand mobility services and change vehicle ownership and travel patterns. However, they are also likely to substantially change the in-vehicle experience and the cost of drivers' time in the vehicle (perceived cost for private drivers, and actual cost for commercial drivers), which could lead to more demand for travel by car and modal shift away from public transport, passenger train and air travel. Freight truck travel could also increase. These travel demand and energy intensity related changes would have large total energy and carbon implications.

Researchers, analysts, and policymakers must begin considering the impacts of vehicle automation on future travel and energy demand, and on the efficacy of different policies and technologies intended to mitigate the effects, if they are adverse from societal perspectives. Given the potentially large influence of vehicle automation on travel behavior, mobility, traffic capacity and end-use energy efficiency, any study on mitigating energy consumption or carbon emissions from the transport sector is likely to miss the mark if the impacts of vehicle automation are not understood. As such, there is a need to get a sense of how automation may affect travel and energy use, by how much, and to identify opportunities to support and guide an environmentally beneficial transition toward vehicle automation.

1.1. Prior work

To date, few studies have quantified the system-wide energy or carbon impacts of automated vehicles. Fagnant and Kockelman (2013) note the potential for reduced per-km emissions and increased travel demand with automated vehicles, but offer few numbers. Their discussion of travel demand effects focuses mainly on the effects of extending mobility to underserved groups and induced demand from capacity improvements. Anderson et al. (2014) mention eco-driving, traffic smoothing, and vehicle lightweighting as potential mechanisms by which automation could reduce energy consumption and emissions per kilometer. They also suggest that vehicle automation might facilitate a transition to alternative fuels, by enabling self-refueling, increasing annual distance traveled per vehicle (accelerating payback periods), and reducing the up-front costs of alternative powertrains (through lighter vehicles the consume less energy overall). Finally, they note that automation could affect travel demand, as a shift to a shared vehicle system could reduce car ownership and travel demand, while several other factors (reduced energy cost per kilometer, increased urban sprawl, the growth of automated taxi services, and decreased use of public transportation) would tend to increase travel demand.

Recent work by Brown et al. (2014) quantified many potential effects of automation on energy consumption, seeking "to estimate upper-bound effects." They considered platooning, eco-driving, efficient routing, and lighter vehicles as potential sources of reduced fuel consumption per kilometer, and faster travel speeds as a source of increased fuel consumption. They also consider the potential for increased travel demand from currently underserved groups and from demand induced by higher travel speeds and reduced congestion. They model the effects of induced demand using a travel time budget framework, assuming that vehicle kilometers traveled (VKT) increases so as to maintain total time spent traveling. Finally, they consider less time spent searching for parking and higher occupancy enabled by shared mobility services as potentially reducing VKT.

In addition to the above studies, there is a broad literature addressing many of the potential changes that automation could enable. Most papers consider these changes in isolation, and impacts on energy demand or emissions are often specific to the particular conditions being considered. We refer to this literature throughout this paper.