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Energy Procedia 142 (2017) 2109–2113

Energy Procedia

www.elsevier.com/locate/procedia

9th International Conference on Applied Energy, ICAE2017, 21-24 August 2017, Cardiff, UK

Could automated vehicles reduce transport energy?

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Abstract

Transport energy use and carbon emissions continue to rise, but both need to be drastically reduced. Conventional proposed solutions, all already used to some extent, include a shift to low carbon transport fuels, major improvements in vehicular fuel efficiency, and modal shift. However, their impact has been marginal. This paper instead examines the extent to which fully automated vehicles could contribute to the environmental sustainability of global passenger transport. Fully automated vehicles were found to lead to *either* an increase *or*, at best, a slight decrease in energy use and greenhouse gas emissions, and so will be of marginal use at best for reducing emissions in a business-as-usual world. Reasons for this conclusion are first, their potentially lower time and money costs would tend to increase vehicular travel, offsetting any energy efficiency gains, and second, that they face serious problems that could delay or even prevent their widespread introduction.

Peer-review under responsibility of the scientific committee of the 9th International Conference on Applied Energy.

Keywords: automated vehicles; global climate change; sustainable transport; transport energy reductions

1. Introduction

Global transport, both passenger and freight, in 2014 used around 110 EJ (EJ = Exa joule =10^{18} J) of final energy, up from 45.3 EJ in 1973. Despite growth in the use of bio-liquids, electricity, and natural gas in transport, over 92% of this final energy is still supplied by oil [1]. Given the continuing dominance of fossil fuels in transport, greenhouse gas (GHG) emissions would have increased in step. Almost two-thirds of global transport energy was used by passenger transport vehicles [2], with the US figure being about 73% [3]. BP [4] anticipates that oil will still supply 88% of global transport fuel in 2035. In a future constrained by global climate change and possibly global oil depletion, transport's energy use and emissions must be greatly reduced, particularly those for passenger transport.

Economists view passenger travel as mainly a *derived* demand: travellers endure time and money costs in order to gain access to desired destinations, such as workplaces and shops. Schafer and Victor [5] have quantified these costs

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Peer-review under responsibility of the scientific committee of the 9th International Conference on Applied Energy .
10.1016/j.egypro.2017.12.613

and used them to project future global travel. They argued that throughout the world, each person spends on average each day about 66 minutes travelling, whether on foot, or by bicycle, private or public transport, or airplane. They further claimed that, at least in the high-income countries of interest in this paper, around 10-15% of household disposable income is spent on transport, including fares, fuel, and vehicle purchase. Overall travel per capita would, however, continue to rise over time, as slower modes were replaced by faster modes, especially air travel. Rising incomes—the authors envisaged real global GDP per capita was rising by an average of 1.4% out to 2050—would enable the additional travel to be afforded while keeping a fixed share of disposable income for travel, so that by 2050, world passenger travel would more than double to reach 105 trillion pass-km. They produced some empirical evidence for these claims of both time and money budgets. Although details of their argument can be criticised [6], the broad idea that people fix some limits on their travel time and money outlays has considerable merit.

In this paper, we examine whether automated vehicles (AVs) could play a major role in reducing both energy use and GHG emissions from global passenger transport, and, to a lesser extent, freight transport. What is novel in this paper is that it explores both the consequences of full automation of passenger travel *and* the likelihood of this occurring. First, if AVs did fulfil their technical potential, their cost and driver time savings would tend to increase, not decrease travel, and with energy use and emissions. Second, widespread use of fully automated vehicles is likely decades away, if ever—too late for climate change mitigation. We thus conclude that AVs are unlikely to reduce transport energy or emissions.

Nomenclature

AV	automated vehicle
EJ	Exa joule $=10^{18}$ J
GHG	greenhouse gas
IHVS	Intelligent Highway Vehicle System
PRT	Personal Rapid Transit

2. Automated vehicles

2.1. History of AVs

General Motors demonstrated the first driverless car in 1935 [7]. Although the lesson we might learn from this demonstration eight decades ago is not to expect driverless vehicles to become common any time soon, some have predicted that driverless cars will appear on roads as early as 2020 [8]. Beginning with anti-lock braking in 1971 [9], there has been a steady rise in automated driver aids, including the automation of speed control, lane keeping, parking, and maintaining safe spacing between vehicles.

An earlier proposal for AVs was the Intelligent Highway Vehicle System (IHVS). This approach envisaged platoons of perhaps 20 cars moving in close formation on suitably instrumented freeways, with field trials successfully carried out in Europe, Japan, and the US in the 1980s. Because of the close spacing, overall air resistance would be reduced, in turn reducing fuel consumption and emissions. Freeway capacity would also be enhanced, because of much lower vehicle spacing [10]. However, off these freeways, drivers would still need to be in full control.

2.2. Justifications for AVs

What is the purpose of modern AVs such as the Google car, apart from showcasing the latest advances in technology? For the Google car, the justifications given are first the road safety benefits: driverless vehicles would enhance road safety because driver error, the most common cause of traffic collisions, would be eliminated. With 1.24 million persons killed on the world's roads each year, and tens of millions more injured, this is a worthwhile aim. Further, 90% of collisions are at least partly caused by driver error [8]. The second justification is to enhance the mobility for people who for whatever reason do not hold a valid driver's licence.

Others consider saving fuel (and so reducing associated greenhouse gases and air pollution) and reducing congestion by saving on road space as important reasons for introducing fully automated vehicles [3, 11]. With the reduced need for safety devices (e.g., air bags) and much lower collision risk, vehicles could be made much lighter, resulting in fuel and emissions savings. AVs would also allow a complete redesign of vehicles, by, for example, eliminating the need for steering wheels and brake pedals, further reducing vehicle mass and cost. Also, as earlier for IHVS, with all vehicles are now able to drive at speed with low spacing, not only would lane capacity increase, but extra fuel savings of up to 10% would be possible, because of reduced air resistance [8]. Further, AVs could be programmed to always drive in an 'eco-efficient' manner, for example by accelerating more slowly.

In this paper, it is assumed for the purposes of argument that full automation has occurred, with no driver needed, and that most of the entire global fleet of private passenger vehicles consists of AVs. (If a driver was still needed for fully automated vehicles for emergencies, or adverse weather conditions, most of the potential benefits of such vehicles from the reduction of mass would be lost, although Wahud et al. [12] have argued that even partial automation could still give some GHG reduction benefits.) It is also assumed that AVs potentially do allow GHG reductions per vehicle-km from changes to vehicle design, closer vehicle spacing, programmed eco-driving (over and above those possible through speed limit reductions), and perhaps, GHG savings from fewer vehicles manufactured.

2.3. Energy and GHG savings for AVs

Several studies have regarded AVs as decisively transforming passenger transport, with Fraedrich et al. [13] arguing that AVs have implications for 'the system of automobility as a whole.' Others have explored the extent to which AVs could help transport sustainability by reducing energy and/or GHG emissions. Greenblatt & Saxena [14] examined driverless taxis and claimed that by 2030, each such deployed taxi in the US would have GHG emissions per vehicle-km 87-94% and 63-82% below those for conventional and 2030 hybrid electric vehicles respectively. These decreases would result merely from three changes: reductions in GHG emissions from electricity, smaller vehicles, and higher veh-km/vehicle per year, without considering the other GHG-saving factors discussed above. Hence, they argued that even if total veh-km rose and vehicle sizes increased, significant GHG reductions would still occur. Levine [3] estimated that AVs could produce either up to 80% reductions in CO_2-equivalent emissions—or a slight increase. For Burns [15], driverless technology would also be integrated with electric vehicles and shared ownership of cars. With widely shared ownership—the average car is presently parked 90% of the time—vehicle numbers could be cut by up to 80%, and parking spaces could be drastically reduced.

Thomopoulos and Givoni [16] have stressed the consequences of the (perhaps optimistic) *cost* savings believed possible with AVs (both for passenger and freight vehicles). 'The potential annual quantified benefits from the use of AVs has been estimated at US$1.3 trillion for the USA, which will come from productivity gains (US$507bn), reduction in accident costs (US$488bn), fuel cost savings due to route optimisation (US$158bn), reduction in congestion related fuel loss (US$11bn).' The largest item is productivity gains from former drivers now being free for other tasks. As discussed in Section 1, travel costs are conceptualised as consisting of money and time costs. The cost reduction estimates just given indicate that both will be greatly reduced with fully automated cars. Hence the GHG reductions from 'route optimisation' and less congestion will be offset to an unknown extent by increased car travel. *Ceteris paribus*, rail and bus travel could lose market share, because their competitive advantages in lower money costs and ability to productively use travel time would disappear [11].

Wahud et al. [12] have stressed that for AVs, energy and GHG reductions 'are not assured, since they generally are not direct consequences of automation per se. Instead, they follow from other changes in vehicle operations, vehicle design, or transportation system design, which may be facilitated by automation.' Indeed, several GHG reduction approaches such as eco-driving, de-emphasized vehicle performance, and vehicle 'right-sizing' would seem to have at best a tenuous connection with AVs, as would the introduction of electric vehicles. They do not rely on full vehicle automation for their introduction.

Cars are not the only surface passenger vehicles experimenting with automation. For four decades, the city of Morgantown in West Virginia has successfully operated a driverless Personal Rapid Transit (PRT) system, and others are now operating at London airport, Masdar city in the UAE, and Suncheon, South Korea [16, 17]. Other things being equal, PRT systems will be less energy efficient than mass transit systems, because of the small number of passengers per car. On the other hand, if PRT systems encourage a shift from cars, GHG reductions should result, since PRT should still emit lower grams CO_2-equivalent per pass-km than private car travel.

Air travel is well ahead of ground passenger travel regarding computers handling the 'driving' task. For air travel, the most important reason for the introduction of existing partial automation was safety and for future full automation with no on-board pilots, significantly reduced operating costs [18]. Fully automated planes should also be somewhat more fuel efficient, but on the other hand, significantly reduced operating costs (and thus lower fares) could drive up air travel, and so raise overall energy use and emissions. However, only automation of car travel will produce major perceived travel time-saving benefits, since for air, public transport and taxi travel, passengers can already use travel time for other purposes.

However, one vitally important effect on car transport, at least, has been to help re-orient the entire transport debate. With AVs, the private ownership of cars is itself questioned. Of course, this questioning of the need to own vehicles was always implicitly recognised, given the existence of taxis, rental cars, shared vehicle ownership, and public transport. Nevertheless, AVs seem to have provided a new focus for both rethinking vehicle design and for purchasing 'mobility services' [19], rather than the vehicles themselves.

3. Discussion

An important remaining consideration concerns the *likelihood* of the technology being introduced; if they never fill more than niche markets, there will be only trivial GHG reductions. AVs are still at the experimental stage. Although AVs such as the Google cars are now licensed to operate in several US states as well as some other OECD countries, there still remain a number of serious problems to be solved before they could become widespread on the world's roads. Marks [20], for example, has stressed that such networked systems are open to malicious hacking, which could compromise safety. And even if all vehicles were automated, human road users, with all their unpredictability, will still remain—pedestrians and cyclists. Goel [21] has pointed out not only the privacy and security problems, but also a nightmare scenario: 'Self driving cars leave us vulnerable to terrorists who can load them with explosives, set their navigation, and then detonate explosives in the middle of busy thoroughfares.'

Even if AVs function perfectly, with no security or reliability problems, *ethical* questions will remain. Specifically, should AV software be programmed to maximise general transport safety or just the safety of the passengers in that vehicle? [11, 22]. Bonnefon et al. [23] have discussed surveys where respondents were asked about AVs that would 'sacrifice their passengers for the greater good.' Their answers indicated that they 'would like others to buy them, but they would themselves prefer to ride in AVs that protect their passengers at all costs.' Further, even if the Internet of Things and ubiquitous computing are the future trend of automobile design [24], subtle 'digital discrimination' [25] in the algorithms used for a number of Internet-based services is already recognised as a potential problem. Because of this and other challenges, Gomes [26], citing a Google spokesperson, has argued that there could be a 30-year time frame for full AV in the US and that its adoption will be incremental, with favourable locations (with good weather) targeted first. It is thus probable that AVs will simply be irrelevant for climate change mitigation from global passenger transport because they will arrive too late to make an impact.

Assuming all these challenges were overcome, AVs could reduce GHG emissions per vehicle-km, mainly because of the increased fuel efficiency make possible by re-designed lighter vehicles and reduced air friction. However, these gains would probably be swamped by far higher levels of car travel, facilitated by lower perceived time and money costs per km, possible increases in car ownership, and possible loss of public transport patronage, all of which are likely in a business-as-usual world. Finally, it is hard to see AVs becoming smaller than present vehicles if they are now perceived as mobile work offices or even entertainment centres. In conclusion, AVs will probably be restricted to niche markets, or even fade away, just as happened with the earlier IHVS initiatives. If we are serious about major transport GHG reductions [27], AVs will likely prove to be merely a distraction from the urgent social changes [28] that are needed.

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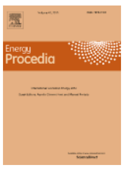

Biography

Patrick Moriarty (research: energy, transport, global futures) is Adjunct Associate Professor in the Department of Design, Monash University, Australia; Stephen Jia Wang (research: Innovation Design Engineering, Tangible Interaction Design, behavioral changes for sustainability) is Joint Head of Programme, IDE & GID, School of Design, and Director of ITIDLab, Royal College of Art, London UK.