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EDITORIAL

Long-term implications of automated vehicles: an introduction

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Introduction

About a century ago, private vehicles started being massively introduced into western societies. Several decades later preventing and/or mitigating adverse effects of this mobility technology became of critical importance for urban and transport policy. Automated driving technology is likely to bring substantial changes in future urban mobility. This Special Issue focuses on the possible long-term implications of automated vehicles (AVs).

Automated driving technology involves hardware (e.g. sensors) and software (e.g. trajectory planning) systems that can assist the driver to conduct the dynamic tasks of driving (e.g. monitor the driving environment, lateral and/or longitudinal motion control). In the lower levels of vehicle automation, the driver monitors the driving environment and s/he is assisted to perform the lateral or longitudinal motion control (Society of Automotive Engineers (SAE) level 1) or both motion controls (SAE level 2). In SAE level 3, an automated driving system performs all dynamic tasks of driving but the driver should be ready to take control of the vehicle. In the highest levels of vehicle automation, an automated driving system performs all dynamic tasks of driving in certain (e.g. in highways; SAE level 4) or in all conditions (SAE level 5) either occupied or unoccupied (SAE International, 2016). The driver is not expected to be available to take control of the vehicle in SAE levels 4 and 5.

Automated driving technology is still in its infancy, although early studies on development of such systems are dated back to the late 1950s. Thus far, research efforts have mainly focused on the technological aspects of vehicle automation (e.g. road environment perception and motion planning). Impacts of automated driving systems on driver, traffic flow characteristics, and fuel efficiency have also been extensively studied especially during the last two decades (Milakis, van Arem, & van Wee, 2017).

The interest on wider social, economic and environmental implications of automated driving is growing as this technology becomes available. This interest reflects concerns that an unconditional, technology-driven introduction of AVs could be in conflict with social and environmental sustainability objectives, ignoring the fact that the transport system is a complex socio-technical system which calls for joint optimization of both the technical and societal sub-systems (e.g. Currie, 2018; Docherty, Marsden, & Anable, 2018; Lyons, 2018; Pangbourne, Stead, Mladenovic, & Milakis, 2018; Thomopoulos &

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Givoni, 2015). For instance, automated driving could reduce travel cost, enhance accessibility and therefore induce new suburban development (e.g. Milakis, Kroesen, & van Wee, 2018; Zhang & Guhathakurta, 2018). Changes in land use and location choices, possible modal shift from public transport to AVs and travel of user groups that currently facing mobility restrictions could induce additional travel demand with significant energy and environmental implications (e.g. Rodier et al., 2018; Wadud, Mackenzie, & Leiby, 2016). On the other hand, road capacity enhancement as well as replacement of part of the fleet by shared AVs (e.g. Boesch, Ciari, & Axhausen, 2016) might reduce future needs for new roads. Long-term implications for public health and social equity could also be important. Possible adverse long-term implications of AVs raise questions about the type, extent, combination and timing of policy responses as well as about the role of urban and transport planners in informing policy responses to this new mobility technology.

This Special Issue brings together eight review and discussion papers that cover a wide array of long-term implications of AVs as well as governance responses to inform deployment of AVs. The first introductory paper provides an in-depth scientometric-bibliometric review of the field. The next three papers focus on long-term travel behaviour and spatial implications of AVs. Subsequently, three papers discuss the planning implications and governance of AVs deployment. The last paper explores the potential and long-term implications of automation in the shipping industry. In the next section, a brief overview of the papers is presented followed by the conclusions of this Special Issue.

Overview of the papers

In the first introductory paper, *Gandia et al.* present a scientometric and bibliometric review, offering an in-depth picture of the main characteristics, evolution and research trends in the AVs field. A total of 10,580 Web-of-Science-indexed papers from 1969 to 2018 were first descriptively and then in-depth analysed using the CiteSpace software. The results revealed a non-fully constructed scientific field with significant heterogeneity, lack of authors' elite and exponential growth of publications reaching a growth rate of 39% compared to the average science growth rate of 8-9% per year. U.S. and China are the most productive countries in terms of publications, yet European countries such as the U.K., Spain and Sweden tend to partner more with other countries in their research outputs. Technical aspects of vehicle automation dominate research with most papers falling into the engineering, computer science, transportation and automation control systems and robotics fields. The U.S. Defense Advanced Research Projects Agency's (DARPA) grand challenges of 2004 and 2007 signalled a shift from laboratory-based studies to empirical, operationalization research of AVs in real conditions. A second shift of research, from technical to non-technical aspects of vehicle automation, is observed after 2015. Emerging topics comprise sustainability, public policies, safety, liability, and business models for AVs explored through social sciences and humanities. The latter shift is accompanied by a migration of research from multidisciplinarity to pluridisciplinarity reflecting cross-discipline collaboration in the exploration of non-technical aspects of vehicle automation.

The next three papers are concerned with travel behaviour and land use implications of AVs discussed from evidence, theoretical and methodological perspective, respectively.

Soteropoulos et al. have reviewed 37 modelling studies on implications of AVs for travel behaviour and land use published between 2013 and 2018. The vast majority of these studies comes from the U.S. and Europe. AVs were mostly found to increase vehicle kilometres travelled (VKT), decrease the share of public transport and active modes, reduce the need for parking spaces and increase population in suburban and rural regions. Yet, these outcomes appeared to be highly sensitive to model assumptions about the AVs business model (i.e. private vs. shared AVs) and changes in the value of time. Assumptions about changes in capacity and the operating characteristics of shared AVs (e.g. waiting time, dispatching model, relocation of vehicles) were also influential for the model results. For example, a context dominated by private AVs inducing significant reductions in the value of time tends to be associated with more VKT, less public transport and active modes use, more vehicles to serve travel demand and thus parking spaces, and a highly dispersed urban form compared to a shared AVs context with more modest decreases in value of time. These researchers recommend more research on generalized travel costs and the perception of travel time in the (shared) AVs era to inform future models. Ideally these surveys should explore such preferences among different socio-demographic groups and use cases of AVs (e.g. different sizes of AVs), taking also into account likely developments such as the possibility for social-emotional matching of passengers in shared AV contexts.

In his literature-based discussion paper, *Singleton* argues that the value of time reductions for AVs could be more modest than already assumed in industry and academia. Moreover, such reductions in the value of time could be mainly realized through changes in subjective well-being rather than via more productive uses of travel time. He contends that more modest reductions in the value of time should be expected for three main reasons. First, the multitasking potential could be restricted by lower ride comfort because of AVs operational efficiencies and capacity enhancements, motion-sickness as well as safety regulations that would limit in-vehicle design changes. Second, sharing an AV with a stranger might prevent users from engaging to in-vehicle activities. Third, evidence suggests that most frequent in-vehicle activities (e.g. daydreaming, viewing scenery, talking to other people) are considered rather non-productive and performed mainly to pass the time and/or to cope with the burden and boredom of traveling. He suggests that travel-related subjective well-being improvements like less stress, higher quality transition time and time being alone could be an alternative path through which value of time reductions might occur. Yet, he adds that such improvements might have already been factored in the existing values of time for car users. Furthermore, eudaimonic subjective well-being aspects of car use such as control, autonomy, and joy of driving might actually be negatively assessed by AV users. He suggests that AV simulation studies of travel behaviour use more modest values of time to test the sensitivity of their results. He also calls for further research in identifying the source of value of time changes in the AVs era, thus informing more effective and sustainable planning policies.

Hawkins and Nurul Habib have presented a critical assessment of a set of representative operational integrated land use and transportation models (ILUT; spatial interaction, econometric and microsimulation models) regarding their capability to inform deployment of AVs. They concluded that none of the existing ILUT models can adequately represent the incremental adoption of AVs as well as the endogenous evolution of transport networks resulting from the introduction of such new mobility technology. They challenge the conventional forecasts of comparative-static equilibrium models arguing instead for models that focus on scenario explorations involving non-linear dynamics, path dependence, and the potential for representing discontinuous change. They recommend stated adaptation surveys on AV preferences to give input to the models, thus accounting for an incremental rather than a discrete addition of AVs. They finally suggest that future models incorporate principles from complex and evolutionary systems theory to account for the dynamism of urban change because of emerging mobility technologies.

The next set of three papers reviews the literature and discusses the planning and governance challenges related to deployment of AVs.

Legacy et al. have explored the role of urban and transport planning in the deployment of AVs through a review of relevant literature in geography, planning and transport journals and semi-structured interviews with public sector planners in the Australian context. They identified three perspectives of AVs research following Kębłowski and Bassens (2018) typology (i.e. the neoclassical, the sustainability and the political economy perspective). They concluded that AVs are not necessarily expected to provide answers to old problems like inequitable access, climate change and fragmentation of physical landscapes. They added that scholarly research is still far from offering a holistic and systematic understanding of AV implications for urban forms. The responses from public sector planners revealed an understanding of the need for regulatory and planning intervention (especially at early AVs development stages) to ensure that AVs deployment will not come in conflict with existing social and environmental targets. Yet, public sector planners have difficulties in identifying their role in shaping the AVs deployment path within a complex public and private governance context. Planners seem to adopt instead a more reactionary position reflecting a "watch and wait" approach (already identified in the U.S. context; Guerra, 2016), which according to the authors create risks for social and environmental sustainability of cities. The authors call for more research on the development of a "cohesive and coherent critical theoretical and conceptual framework" facilitating reconciliation between AVs deployment and public purpose planning.

Taeihagh and Lim have reviewed literature on AV risks for safety, liability, privacy, cybersecurity and industry influence and the associated government responses from Australia, China, the EU, Germany, Japan, South Korea, Singapore, the U.S., and the U.K. These researchers developed a framework classifying government responses to AV risks into the following categories: no-response, prevention-oriented, control-oriented, toleration-oriented, and adaptation-oriented. According to the analysis of government responses, policymakers tend to conceive AVs as a threat rather than as an opportunity to change the system by embracing uncertainty associated with AVs. Therefore, in most instances, they have adopted either a (light) control-oriented strategy involving non-mandatory guidelines and workgroups to further explore AV implications or a no-response strategy. Such non-binding strategies, for example with respect to safety risks, reflect an effort to allow adequate space for innovation (especially in the U.S., U.K. and Chinese contexts) but also possibly suggests less emphasis on citizens' protection which is more evident, for example, in EU's regulatory approach for safety of AV testings. Government regulations to control privacy and cybersecurity risks are mostly non-AV-specific covering other systems as well, while most governments have not responded to employment risks of AVs yet.

Cohen and Cavoli have explored the longer term effects of a mass level 5 AVs adoption scenario on congestion and accessibility within a government non-intervention context (i.e. laissez-faire). To this end, a systematic review of relevant literature (432 documents) and four workshops with stakeholders (from academia, central and local government, transport operations, NGOs, consultants) were conducted in the U.K. and France. These researchers concluded that congestion in a laisser-faire approach would likely increase because of higher travel demand and reduced network efficiencies. Accessibility changes would range from neutral to negative further increasing existing inequalities. For example, the cost of owning or use of an AV would likely remain high for those not currently having access to conventional private modes of transport. Moreover, possible further suburbanisation of activities would create additional accessibility difficulties for non-AV users. The authors suggest five categories of possible government interventions/tools to anticipate and prevent adverse effects of a laissez-faire scenario: planning-land use (e.g. density requirements), regulatory-policy (e.g. ban empty running of AVs), infrastructure-technology (e.g. provide high-quality mass public transport), service provision (e.g. provide priority groups with access to AVs), and economic instruments (e.g. subsidised or free AVs use for priority groups). The extent and time of interventions as well as the effectiveness of the combination of policies remain open questions. Assessment of possible interventions against different scenarios of AV futures could inform government actions. The challenge for identifying the optimal balance between fostering mobility innovations and ensuring societal well-being might be higher for western capitalist governments given dependence in a less-interventionist path.

Finally, the last paper of this Special Issue reminds us that automation is not restricted to road (passenger) transport but can extend to other forms of transport such as sea (freight) transport with significant long-term implications as well.

Ghaderi has investigated the potential of autonomous vessel technology in short sea shipping (SSS: "the maritime transport of goods over relatively short distances, as opposed to the intercontinental cross-ocean deep sea shipping", Eurostat, 2018) focusing on crew cost savings as well as on possible deployment barriers. He first conducted a literature review highlighting SSS challenges (e.g. crew cost, productivity, environmental performance, energy efficiency) and the possible role of autonomous vessels in dealing with those issues. He then developed a quantitative model to compare crew costs (accounting for about 50% of total operating expenses) between conventional and continually unmanned ships (CUS). His model comprised direct costs (e.g. wages, travel expenses, victualling, training and fees associated with unions), indirect costs (i.e. social dues, medical tests, hiring processes, sick pay, port expenses and agency fees) and employment-related costs (i.e. crew selection, rotation, travel arrangement and other supplies). Based on the application of the model in an Australian sea route, the author concluded that autonomous technologies in SSS would be more efficient from crew cost perspective (a) in markets with low and uncertain rather than high and stable demand and (b) in shipping network operations, because one shore control centre would handle multiple CUS simultaneously. Yet, regulatory (e.g. the legal requirement of a master in charge of the vessel), workforce (e.g. new skills for operating CUS, redundancies of seafarers), port operations (e.g. new systems for safe navigation of autonomous vessels), liability (e.g. piracy, cybersecurity incidents) and vessel productivity issues (e.g. CUS will operate in lower sailing speeds) still need to be resolved before deployment of autonomous technologies in SSS.

Conclusions

This Special Issue focused on long-term implications of AVs. It is indeed challenging to summarize such a rich set of ideas, analysis and results. In the next two paragraphs, I will outline some general conclusions and then I will discuss more specific conclusions about long-term travel behaviour, spatial, planning and governance implications of AVs. I will close this section with some thoughts about future research on long-term implications of AVs.

Research on AVs represents a very dynamic field dominated so far by studies on technical aspects of vehicle automation (Gandia et al., this issue). A gradual shift of interest towards non-technical aspects of vehicle automation such as sustainability and governance is observed after 2015. Non-technical aspects of vehicle automation are mainly explored through social science and humanities perspectives with increasing cross-discipline collaboration.

The studies included in this Special Issue focused more on the highest levels of automation (SAE level 4 or 5) possibly recognizing the potential for significant long-term implications mainly at these levels or that level 3 of vehicle automation will be skipped altogether. A wide array of qualitative and quantitative methods was reviewed and/or used, possibly reflecting the complexity of research questions associated with long-term implications of AVs. Several papers in this Special Issue provided country-specific evidence which is a welcome step in the AV literature that has been mostly country agnostic.

Evidence reviewed in this Special Issue suggests that AVs will likely be associated with more VKT, less use of public transport and active modes, less parking demand and further suburban development (Soteropoulos, Berger, & Ciari, this issue). Yet, such simulation-based evidence is highly sensitive to assumptions about the AVs business model (i.e. private vs. shared AVs) and changes in the value of time, highlighting the uncertainty associated with early estimations of long-term implications of AVs.

The value of time changes could be more modest than typically assumed and linked to changes in subjective well-being rather than to more productive use of time in AVs. Further research is suggested to explore the source (and subsequently the magnitude) of changes in the value of time in the AVs era (Singleton, this issue). Moreover, the AVs deployment path could be far more dynamic than initially assumed, influenced by multiple factors (e.g. socio-demographics, technology preferences, path dependence, regulation, liability; Ghaderi, this issue for an analysis of those factors in the case of automation in SSS). Stated adaptation surveys are suggested to account for such incremental evolution of AVs compared to stated choice experiments that consider AVs as discrete change (Hawkins & Nurul Habib, this issue). Such a dynamic pathway of AVs deployment could have different implications for urban form than currently assumed. Hawkins and Nurul Habib (this issue) recommend that principles from complex and evolutionary systems theory are incorporated into ILUT models to account for the intertemporal nature of AVs adoption.

Long-term implications of AVs unavoidably raise questions about the governance of AVs. The key question refers to the optimal balance between enabling AVs and ensuring (fair distribution of) societal benefits from this mobility technology. This question should be answered early enough, shaping evolution of this technology accordingly. Most advanced countries with respect to AVs technology have adopted non-binding or no-response strategies to critical issues of AVs deployment such as safety, liability, privacy, cybersecurity and employment implications (Taeihagh & Lim, this issue). Furthermore, early evidence suggests that public sector planners cannot clearly see their role in shaping the AVs deployment path, adopting a "watch and wait" approach. Yet, planners are aware that planning and regulation would possibly be necessary to avoid conflicts between AVs deployment and existing social and environmental targets (Legacy, Ashmore, Scheurer, Stone, & Curtis, this issue). Indeed, a laissez-faire governance approach of AVs seems to produce adverse effects for congestion and neutral to negative effects for accessibility enhancing inequalities (Cohen & Cavoli, this issue). Yet, the type, extent, combination and timing of policy responses to AVs within a more interventionist governance approach are still to be further explored.

After a long period of overly optimistic discussions and mostly technological oriented research on AVs, there are early signs that deployment of AVs will likely be much more complicated than initially expected, possibly involving adverse long-term implications for social and environmental sustainability. Early exploration of those implications and of the associated policy responses is important to not only prevent unwanted consequences but also shape development of this new mobility technology in a socially desirable way. This Special Issue served this purpose by reviewing evidence and discussing long-term travel behaviour, spatial, planning and governance implications of AVs. Future research could further acknowledge the socio-technical nature of the AVs transition answering questions about the social (instead of consumer only) acceptance of AVs, the possible long-term implications for public health and social equity as well as the planning and policy response strategies and tools for socially beneficial integration of AVs. Future research could also explore the role of AVs within different policy pathways towards desirable healthy, inclusive and sustainable urban futures. Cross-country (or cross-city) comparisons of long-term implications of AVs acknowledging differences in socio-demographic, urban and transport characteristics, governance structures, cultural as well as climate factors would give further useful insights into the field. Cross-discipline collaboration, bringing together the engineering, social sciences and humanities perspective would allow deeper and more holistic understanding of the long-term implications of AVs.

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