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Smart meters and public acceptance: comparative analysis and governance implications

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Although smart meters for electricity have received widespread acclaim as a means to achieve more resilient and sustainable electricity consumption, public opposition has emerged in several countries. In this article, I examine the reasons for public opposition in North America and the role of concern with health risks. The article provides an analysis of reasons given for opposing smart meters by 75 US and Canadian organisations listed in the 2013 EMF (electromagnetic field) Safety Network, a review of all news reports (499) in the Lexis-Nexis database relating to smart meters in seven US states and one Canadian province from 2010 to 2013 and case studies of policy responses in the same seven states and province. Thirty-one of the organisations in the EMF network focused mainly on health concerns about EMFs, and 44 organisations identified broader concerns as well as health risks. The more politically conservative groups focused on issues relating to privacy and government intrusion. Newspaper reports also identified health risks, although they also identified issues relating to cost overruns and privacy. The study of newspaper reporting in the seven US states and one Canadian province indicated that relevant agencies had responded to public concerns by developing opt-out provisions for meter installation, in some cases after protracted public campaigns. I consider possible patterns of opposition for future investigation: opposition may be higher where the roll-out of smart meters is rapid and without an opt-out provision; technological differences (for example, wired versus wireless) may contribute to levels of public opposition; and challengers to incumbent parties of either the right or left may also contribute to public opposition. In the 'Conclusion' section, I compare two policy strategies, one of which views public opposition as a lack of good communication from utilities, and the other which views it as an opportunity for innovation in systems design and improvements in governance policies.

Keywords: smart meters; health; social movement; public understanding; risk

Introduction

As an important element of the smart grid, the smart meter enables communication between the electricity grid and appliances in a building. Notwithstanding the many potential benefits, the roll-out of smart-meter programmes created public opposition that often centres on health risks. The opposition is linked to other forms of public opposition to risks associated with other electromagnetic fields, such as those associated with mobile phone masts and high-voltage electrical wires. However, there are also significant differences because opponents of smart meters cite concerns about privacy, security and home utility costs that do not appear in public opposition to other forms of 'electrosmog'. Thus, an analysis of public opposition to smart meters can provide new insights into research on

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health, electromagnetic risks and the public understanding of risks and reception of new technologies.

In this article, I will present the first general comparative analysis of public opposition to smart meters in North America, the region of the world where opposition has been most developed to date. Smart meters and the smart grid offer many important sustainability benefits (such as time-of-day pricing and the capacity of the utility to turn off appliances during peak load), but as smart-meter installations have spread, so has public opposition. In this article, I examine the relationship between health risks and other kinds of risks and concerns that have emerged in public opposition to smart meters in North America, and I examine the response of agencies to public opposition. In this article, I will focus on two key issues:

- the primary reasons given for opposition by anti-smart-meter organisations in North America;
- the policy responses that have emerged at the state and provincial level.

After considering these issues, I will develop hypotheses about the conditions under which opposition emerges and discuss possible implications of public opposition for the design and governance of the smart grid.

Context: public opposition to smart meters

Public opposition to smart-meter technology is complicated from the perspective of studies of health, risk and society, because health risks are frequently linked to other risks and public concerns, especially those associated with privacy and security. Because smart-meter technology was installed in some locations before privacy and security rules were completely developed, regulatory agencies have had to play catch-up to the numerous issues that have emerged (see National Institute of Standards and Technology 2010, Trans-Atlantic Consumer Dialogue 2011). There is pervasive anger at being forced to accept devices that can report on activities by appliance in a household and can lead to ‘Big Brother’ knowledge about what people are doing in their homes. When sampling of household-level consumption occurs at short intervals, such as every 15 minutes, it possible to detect when people are at home and what appliances they are using. The knowledge raises new issues of domestic privacy that have not been evident in other health controversies involving electromagnetic fields, such as the installation of mobile phone masts or high-voltage electrical wires. In 2010, the State of California approved the first state government privacy standards (SB 1476), which provided for an opt-in rule for sharing of consumption information with commercial third parties (Forbush 2011). The Province of Ontario also developed a privacy guidance policy (Ontario Information and Privacy Commissioner 2012). The broader issue of the smart grid also raises general political concerns such as the level of centralisation or decentralisation of the energy system (Stephens *et al.* 2013).

The level of public concern with smart meters is variable, and it ranges from scepticism about benefits to mobilised opposition, such as demonstrations at the National Grid Week conference in 2012. For the United States, a survey of the country as a whole indicated that people supported the claimed benefits of smart meters but were often sceptical that they would see the benefits (Lineweber 2011). The survey also showed that most customers had reservations about costs and privacy (questions about health were not included), that support was higher among Democrats with pro-environmental views, and that about 20% of the customers were strongly opposed to installation. The high level of scepticism about the actual delivery of promises and the segment of strongly opposed customers suggest that conditions are ripe for mobilisation when installation is mandatory. The only systematic research to date on the reasons for opposition that includes health concerns is limited to California, where an analysis of several data sets of public commentary indicated that health concerns were the primary reason for public opposition (Hess and Coley 2014). Other issues were also raised in the following order: privacy, accuracy (resulting in price spikes), security (capacity for thieves to know when people are home), transmission (interference with other household electronics), environment (criticisms of actual effects on carbon reduction) and hazards (fires).

One source of opposition to smart meters is people who self-identify as electrosensitives or as otherwise harmed by ‘electrosmog’ (de Graef and Bröer 2012, Lezaun and Soneryd 2007, Soneryd 2007). However, opponents of smart meters in the United States and Canada include many persons who do not self-identify as electrosensitives and who argue that their health concerns are scientifically based (Hess and Coley 2014). Opponents sometimes point to the general research on health and non-thermal effects of non-ionising electromagnetic fields, especially research on mobile phones (see, for example, Maine Coalition to Stop Smart Meters 2013b). There are also experts with appropriate credentials who document non-thermal risks of microwave radiation (BioInitiative Working Group *et al.* 2012), and there are signs that scientific advisory bodies are increasingly recognising some non-thermal risks for low-dose microwaves from mobile phones (International Agency for Research on Cancer 2011). However, many scientists, including but not limited to those who represent industry, also note that there is research on the relative safety of electromagnetic fields at non-thermal doses. Thus, the expertise on health risks for the non-thermal effects of microwave radiation remains sharply divided, and the public mobilisations are supported by some researchers who think that there is enough potential documented risk from microwave radiation to warrant a more precautionary regulatory approach (BioInitiative Working Group *et al.* 2012).

There is widespread industry scepticism of public expressions of concern with health risks for smart meters. Industry research has found opposition rates of only 10% and has indicated that opposition is due to lack of knowledge (General Electric 2010). Thus, from an industry perspective, the problem is the lack of public knowledge and a public misunderstanding of science. To some extent, the social science literature on electromagnetic fields also has been fairly sceptical of the scientific basis of health concerns (see, for example, Burgess 2002, 2003). Social scientists have pointed to the lack of technical knowledge among the public, and some have suggested that media coverage may overemphasise health risks (Elvers *et al.* 2009, Cousin and Siegrist 2010, Claassen *et al.* 2012). Social scientists who work from this approach may explain public discourses of health risks as outcomes of other social factors, such as lack of political power, media sensationalism and/or poor understanding of science.

The theory of ‘phantom risk’ can lead to interesting research questions about how social factors (such as misunderstanding of science and power inequalities) affect risk discourse, but the attempt to explain public expressions of health risk as due to other factors can be dismissive of the health risks in a way that is isomorphic with the dismissive approach taken by industry. In contrast to ‘phantom risk’ approaches, which assume that public concerns with health risks have no scientific basis, in this article, I do not adopt a position on the scientific controversy about the health effects of non-thermal electromagnetic fields, and I do not attempt to evaluate public concerns as either well founded or ill founded with respect to science. Rather, I treat health concerns as

Durkheimian ‘social facts’ that have social and political effects. This approach recognises that public concerns with smart meters are, in some cases, connected with more general public opposition to having their communities or homes forcibly accept technologies without local consent and without a democratic decision-making process (Drake 2006, 2011). However, this approach does not reduce health concerns to differentials in political power. Rather, it seeks to understand the pattern of bundling of health concerns with other concerns, and it seeks to understand the political effects of these bundles of concerns. In contrast with approaches that wish to explain away public discourse on health risks as due to other social factors, this more comprehensive approach to public understandings of electromagnetic fields and health risks can provide insights that might not otherwise be visible. Specifically, in the ‘Discussion’ and ‘Conclusion’ sections, I will draw attention to technological design choices that are related to the health concerns. These design issues are relatively invisible in a phantom risk approach, which seeks explanatory factors only in the social world.

Methodology

This article draws on two related analyses. The first analysis provides data on the reasons given for opposition to smart meters. It begins with the EMF (electromagnetic field) Safety Network’s (2013) listing of anti-smart-meter organisations and information sites, which included 87 entries for American states and Canadian provinces. All of the entries were reviewed and coded for the reasons given for opposition to smart meters and for political orientation. I also reviewed the Lexis-Nexis database using the search terms ‘smart meter and (state/province)’ for seven US states and for British Columbia. There was no starting time limit, but most reports began in 2010, so the analysis effectively covered the 4-year period from 2010 through late 2013. This search strategy resulted in a data set of 499 articles (British Columbia, 96; California, 215; Maine, 68 Maryland, 19; Michigan, 32; Nevada, 34; Oregon, 15; and Vermont, 20). I made the following exclusions: duplicate content, no discussion of public concern or opposition, and no specific discussion of the state or province in question (such as a general article that only mentions the state briefly). These criteria reduced the data set to 120 articles, which were coded based on the reasons for opposition: cost, fire hazard, health, privacy, security (theft, terrorism) and other. The category of ‘other’ included one statement about the non-green conditions of smart-metering manufacturing and three statements about transmission interference with wireless routers in homes.

To examine policy responses to public opposition, in the second analysis, I undertook brief case studies to explore the sources and reasons for public opposition and the policy decisions for the seven states that have passed legislation or have public utility commission decisions that support opt-out policies (California, Maine, Maryland, Michigan, Oregon, Nevada and Vermont). I also considered British Columbia because it has the most active anti-smart-meter movement in Canada, and the provincial utility allowed an opt-out provision after a long public mobilisation. Opt-out rules were under consideration in other states by late 2013 (Florida, Hawaii, Georgia, Illinois, Indiana, Louisiana, Massachusetts, New York and Pennsylvania), but information is much more sparse on those states, and analysis of those states and additional Canadian provinces is not undertaken in this article. I do not consider in this article action by attorneys general who have made statements against or taken actions against smart meters, generally based on the likelihood of excessive cost (Arizona, Connecticut, Illinois and Michigan).

In this article, I take a comparative approach, which provides a context in which more detailed and localised studies might be situated. This approach can also help avoid a tendency towards premature generalisation, which is beginning to emerge, such as arguments that opposition is based only on right-wing ‘Tea Party’ organisations.

Findings

Reasons for opposition

The EMF Safety Network provided links to 87 websites that expressed anti-smart-meter sentiment. Of those sites, 12 were not counted because they provided incomplete information or were not functioning. The remaining websites were maintained by individuals, formal non-profit organisations, community-based networks and state-level coalitions. Of the 75 websites that provided reasons for opposition, only 31 cited health as the only or primary reason for opposition, and 44 websites provided a more comprehensive list (including health). The health emphasis tended to be found in sites developed by persons who had experienced health effects and then became opponents of smart meters, and by organisations that were concerned with general issues of electromagnetic field safety for a wide range of devices (such as mobile phones and mobile phone masts). More comprehensive discussions of reasons for opposition tended to be found in the state-level anti-smart-meter coalition organisations, in community coalitions and in right-wing organisations. The lists of reasons for opposition other than health nearly always included privacy, and they often included cost, safety (especially fire risk) and security.

In the United States, researchers have become aware that anti-smart-meter sentiment has been especially strong among some right-wing groups, but in this data set, the characterisation only applied to seven organisations. Opposition to smart meters predates the development of the ‘Tea Party’ movement, but the issue has been embraced by right-wing pundits and local Tea Party groups. In the seven cases, the websites focussed on privacy and government intrusion issues and were often critical of Local Agenda 21 (the United Nations effort to build sustainability at the local level) and of alleged government plans to spy on individuals. These seven groups were active in California, Illinois, Michigan, Nevada and Oklahoma, and they were particularly active in Texas, where opt-out legislation was being considered in the state legislature (Wilder 2012, Jeffrey 2013). In Texas Thelma Taormina, founder of the Houston-based *We the People Are the 912 Association*, gained fame in Tea Party circles when she used a gun to stop a smart meter installer from entering her property (Hooks 2013). In the town of Fountain, Texas, opponents gained enough signatures to place on the ballot a measure that would require replacement of the new digital meters with old analogue meters, citing the need to stop spying by Big Brother (Best 2013).

My analysis of newspaper reporting in the seven US states and British Columbia showed that in media reports of public opposition health concerns were paramount, a finding that is consistent with our research for California (see Hess and Coley 2014). However, in some reports, especially longer articles, issues of privacy, cost and security were also important. The primacy of health concerns in media reports was not limited to California but was found in all states and provinces. When the reports in the other US states are aggregated (see Table 1), the state with the largest number of reports (Maine) had twice as many mentions of health concerns than privacy, the second largest factor. Newspaper coverage tended to include cost overrun issues at the start of a programme of

Table 1. Reasons for public concern in news reports*.

Public concern	British Columbia	California	Other states
Number of articles	49	37	34
Cost (overruns, accuracy)	16 (33%)	15 (41%)	8 (24%)
Fire hazard	3 (6%)	1 (3%)	3 (9%)
Health	37 (76%)	31 (84%)	26 (76%)
Privacy	11 (22%)	11 (30%)	16 (47%)
Security (theft)	3 (6%)	3 (8%)	6 (18%)
Other	1 (2%)	0	3 (9%)

Note: *Percentages are the number of articles mentioning the concern divided by the total for the regional category (e.g., 16/49 for cost for British Columbia). Because some articles identify more than one issue, the percentages total to more than 100.

smart-meter installations, whereas there was more reporting of health concerns after the meters were installed.

Case studies: pattern of opposition and policy responses

In this section, I examine in more detail the pattern of opposition and policy responses in the seven US states and British Columbia. In most of the states and the province, organisations that opposed smart meters focused on health risks, but some statewide organisations also had a comprehensive approach of listing a wide range of reasons for opposition. Right-wing groups in two states focused on privacy and government intrusion, and a business organisation in one state focused on cost concerns.

In three cases, there was an initial phase of local government resolutions against mandatory installation, which preceded a policy response at the state or provincial level. In all cases discussed below, there was a policy response that enabled customers to opt out of mandatory smart-meter installations. The response came from the utility (British Columbia, Michigan), state government legislation (Vermont) or the public utilities commission (other states). In Vermont, the opt-out arrangement also includes a no-fee clause.

In each of the states and the province, there was a different pattern of events, with different types of opposition and different policy responses, and in the remainder of this section, I will discuss each in turn.

In *British Columbia*, the provincial government adopted a rapid installation approach, setting a deadline of 2012 for the installation of smart meters, and the energy utility responsible for the installation did not allow an opt-out provision. These decisions stimulated a strong opposition movement. The province's Coalition to Stop Smart Meters (2013) provides multiple reasons for opposition, including (in alphabetical order) cost, democracy, environment, health, loss of jobs, privacy, safety and security. The other four main anti-smart-meter organisations active in British Columbia focussed on health issues, but one also included concerns with privacy and fire hazards. On the issue of fire hazards, there were some media reports of fires associated with smart meter installations, but experts argued that other faulty wiring issues were to blame (McInnes 2012, Simpson 2012b).

Public opposition in British Columbia was linked to provincial party politics, because the roll-out of smart meters was supported by the governing Liberal Party (the right-wing or neoliberal party). The government's decision not to let the British Columbia Public

Utilities Commission review and oversee the project fuelled public opposition and anger. Opponents locked their meters and posted signs, and BC Hydro responded by sending out letters telling the opponents that the utility would break the barriers and would install the meters. In turn, the letters provoked widespread public outrage. John Horgan of the opposing party, the New Democratic Party, stated that if his party were to gain power, he would ask the province's public utilities commission to take over the programme (McInnes 2013, Shaw 2013).

The opposition group, Citizens for Safe Technology, appeared before the British Columbia Human Rights Tribunal to link health concerns to human rights violations by arguing that the installation of wireless smart meters violated the rights of electrosensitives. The Tribunal responded to this argument by telling the group it should narrow its claim to people medically diagnosed with electrosensitivity who have been advised by their physicians to avoid wireless technology (Simpson 2012a). The British Columbia Office of the Information and Privacy Commissioner (2011) also investigated BC Hydro, found some issues of non-compliance with privacy standards and made some recommendations. The British Columbia Confederation of Parent Association Committees also entered into the debate in 2012 by issuing two related resolutions that reinforced general concerns with health and electromagnetic fields. Resolution 2012.17 requested that each Board of Education have one public school at each education level (including elementary, secondary) free of Wi-Fi, cordless phones and mobile phones, and that this school use only wired connections. The second resolution, 2012.18, called on Boards of Education to cease the installation of Wi-Fi in schools where it was technically feasible to do so (British Columbia Confederation of Parent Advisory Councils 2012).

In the absence of a response from the provincial government, opponents of smart meters in British Columbia turned to local resolutions by city governments. In 2011, the Union of BC Municipalities voted in favour of a moratorium on smart meters, but BC Hydro ignored the resolution. By 2013, 59 municipalities had passed resolutions in favour of a moratorium or opt-out law (Citizens for Safe Technology 2012). The model ordinance cited 'the potential for wireless smart meters to cause harm or to compromise security', and it requested that the province institute 'a moratorium on mandatory installations of wireless meters' and that customers be offered 'safer alternatives at no cost to them' (Citizens for Safe Technology 2012). Thus, the wording of the resolutions clearly signalled a concern with health risks. In January 2013, BC Hydro decided that it would not install the remaining 85,000 smart meters in its jurisdiction without permission of the homeowners. It had already installed 1.7 million smart meters, or about 95% of the total planned installations, at a cost of approximately 1 billion Canadian dollars (CBC News 2013). The utility refused to remove smart meters from homes in which they were already installed, and in July 2013, a yoga instructor with health concerns launched a lawsuit, inviting others to participate in class action against BC Hydro to force the removal of the smart meters they had installed in their properties (Luk 2013).

As we have shown, in *California*, health reasons feature in several data sets that record public opposition to smart meters (Hess and Coley 2014). The review of the EMF network for this article identified 18 anti-smart-meter organisations active in California, and in their websites, 10 of these organisations identified health issues as the main reason for their opposition. The remaining eight organisations provided a wider range of reasons. Only one of the organisations in this group was clearly identifiable as politically right wing.

In California, the state's Public Utilities Commission did not respond quickly to public concerns, and the lack of response triggered local government responses from four counties, nine cities and one tribal community, which resolved to make smart meters illegal within their jurisdictions. Other counties and over 30 other cities and towns developed resolutions to have the utilities stop the smart-meter installations, and some also issued statements in favour of the state government bill that required an opt-out policy but failed to pass through committees in the state legislature. In 2012, the California Public Utilities Commission responded to public opposition by approving an opt-out provision that allowed customers to keep their analogue meters for an initial fee (75 US dollars) and an additional monthly fee (10 US dollars).

Although Californians gained the right to opt out, some customers experienced difficulties with the implementation of the opt-out provision. The Center for Electrosmog Prevention (2013) reported that customers were not allowed to read their own meters, even though they had previously been allowed to read their meters, in some cases, for more than 30 years. The centre reported that some customers had taken the entire day off work, and then no one from the utility had come to read their meter. Some customers also reported difficulty obtaining the opt-out (The Center for Electrosmog Prevention 2013).

In *Maine*, the Smart Meter Safety Coalition focused on health effects, whereas the Maine Coalition to Stop Smart Meters (2013a) cited a range of issues including ‘adverse health effects, fires in the home, damage to appliances, electrical problems and increased utility bills’. In 2011, opponents appeared before the state’s Public Utilities Commission to challenge the utility’s right to install smart meters; opponents made the argument that installation was a violation of their property rights. The commission determined that customers could opt out, but that the utility could charge a fee. Customers appealed against the opt-out fee before the state’s Supreme Court, which ruled in favour of the Commission but also instructed it to address health and safety concerns (McCarthy and Hansen 2012). After winning the right to opt out, opponents shifted their goal to gaining approval for a no-charge opt-out bill under consideration in the legislature in 2013 (Thistle 2013).

In *Maryland*, there is only one major anti-smart-meter organisation, Maryland Smart Meter Awareness, and it called for a moratorium, or at the minimum an opt-out provision, until smart meters were proved to be safe and reliable. Its approach was comprehensive, based on concerns with health, privacy, national security, safety, rate increases and effects on the planet’s ecosystem. A retired attorney from the Environmental Protection Agency, Jonathan Libber, led the state’s opposition campaign and gave it considerable credibility. The Maryland Public Utilities Commission ruled that customers should be allowed to have an alternative to standard smart meters. About 3% of the customers wrote to the utility to request deferral of the installation of a smart meter without charge. At the time of writing, a committee in the state government’s House of Delegates was studying the issue for further action (Hopkins 2013).

In *Michigan*, individuals who experienced health effects formed the Smart Education Network, whereas Tea Party members formed the W4AR, which focussed on privacy issues and government spying. There were other organisations opposing smart meters for a variety of reasons including health. By mid-2012, nine local governments had approved a moratorium on smart meters and requested studies of health effects (Greene 2012). The Association of Businesses Advocating Tariff Equity was also critical of smart meters, based on the grounds that they represented an unnecessary cost for electricity in a state that already had high rates (Greene 2012). In response to consumer and business opposition, the Michigan Public Service Commission (2012) conducted additional research and gathered public comments; its analysis of 397 comments listed the desire for an opt-out provision as the top issue expressed in the comments. The tally of objections raised showed that health concerns were paramount (77% of responses), followed by privacy (49%), legality (27%), security (18%) and cost (17%). Based on recommendations in the report, the utility Detroit Edison responded in 2012 with a plan for an opt-out provision, but State Attorney General Bill Schuette argued that the fees were excessive (Biolchini 2013). The Smart Meter Network also appealed in the Michigan Court of Appeals against the decision by the state's public service commission to accept the opt-out fee plan (Freed 2013). In February, 2013, state legislator Tom McMillan (2013) introduced a bill that would eliminate opt-out fees and would limit the number of times a utility could read a meter each month.

In *Nevada*, the right-wing Nevada Constitution Alliance (2013) opposed smart meters primarily on grounds of privacy and government intrusion, but it also listed health and other concerns. Two other organisations expressed health concerns as their main issue. In 2012, the Public Utilities Commission allowed customers to opt out with a digital, wired meter, but after a request from the Bureau of Consumer Protection, the commission decided in 2013 to allow consumers to request a new, sealed analogue meter but with an opt-out fee (an initial 53 US dollar fee, plus 9 US dollar monthly fee). An estimated 9000 customers out of 1.45 million are on the postponement list (Robison 2013).

In *Oregon*, a 100-member group formed the Families for Safe Meters to oppose smart-meter installations. In one article, they cited vulnerability to cyberattack and health effects as their primary concerns (Dietz 2012). The state's public utilities commission required utilities to implement an opt-out provision, but opt-out fees were controversial. Portland General Electric had a monthly charge of 51 US dollars for the opt-out, but the city council of Ashland developed a no-charge policy for opt-out (City of Ashland 2012).

In *Vermont*, three opposition organisations identified a range of concerns, including privacy, security, health, cost, energy saving and electrosensitivity. In 2012, the Vermont state government approved a law that allowed customers to opt out without incurring a charge (Vermont State Legislature 2012). In Vermont, the opt-out rate in 2013 was 4%, whereas in Maine, where the opt-out fee is 40 US dollars for the initial rate plus 12 dollars per month, the opt-out rate as of 2013 was 1% (Thistle 2013). In 2011, two of Vermont's rural electricity cooperatives chose wired technology over wireless, even as the state's larger utilities, which serve a higher percentage of urban customers, opted to use wireless technology. The cooperatives cited cost considerations rather than health issues. Because the cooperatives serve customers in hilly, rural terrain, wired technology was deemed more effective (Dillon 2011).

Discussion

In summary, the analysis of opposition to smart meters in North America reveals several new findings: opposition is not restricted to one geographical region such as the West Coast; concern with health risks are paramount, but other important concerns are frequently raised; frequently, campaigns of opposition are protracted, and in some cases, they can involve city–government ordinances in an attempt to gain a response at the state or provincial level; and in several cases, the government, public utilities commission or utility have responded with opt-out provisions. The rise of public opposition to smart meters is, to date, an understudied topic in the developing literature on the design and governance of smart grids, and at this point, the literature can benefit from a discussion of implications and questions for future research. Four main implications for additional research emerge from this comparative analysis.

Implication 1: Public opposition is heightened where there is no opt-out provision, as in the cases of British Columbia, California and Maine. The diffusion of opt-out rules to minimise public opposition suggests that institutional isomorphism dynamics (that is, the spread of opt-out responses due to the copying of other policies instead of or in addition to grassroots opposition) will become increasingly evident, and countries and states may even anticipate public opposition by instituting opt-out rules. Such rules are likely to reduce opposition based on privacy and security more than on health, because opponents concerned with health risks are also concerned with spillover effects from meters installed in neighbouring homes.

Implication 2: Although health-related reasons are likely to be prominent in most North American opposition campaigns, several factors may mitigate the importance of public concern with the health risks of smart meters. In this data set, organisation type was related to type of concern. Specifically, broad state-level groups tended to embrace the full range of reasons for opposition as a framing strategy to build broader coalitions, and likewise right-wing political groups tended to be more concerned with privacy and 'Big Brother' issues. There may also be national differences with respect to concern with health risks. Evidence from countries outside North America suggests that public concern with health risks in comparison with other types of risks and concern may be lower, but the available evidence is currently limited. For example, in Australia, large-scale wireless smart-meter installations at the time of writing (2013) were limited to the state of Victoria, where the state's auditor general was critical of the costs to consumers, and public opponents frequently cited cost overruns and rate increases as the source of their opposition (West 2012, Smith 2013). In the United Kingdom, the consumer organisation *Which?* opposed an immediate roll-out, and 500 respondents to its opposition statement stated that their main concern was cost (Driscoll 2012). In the United Kingdom, a survey of 1000 consumers by Tripwire, Inc. (2013) identified concerns with privacy, security and control of household data, but this survey did not include questions about health concerns. In the Netherlands, opposition also centred on privacy issues with pushback in 2006 and 2008 against the original legislation, which mandated installation and required that information from household electricity consumption be forwarded every 15 minutes (Cuijpers and Koops 2012). The Dutch Data Protection Authority determined that the laws violated privacy rules, and the Minister of Economic Affairs changed the reporting to daily intervals with an opt-in provision for 15-minute intervals plus guidelines for data use (Cuijpers and Koops 2012).

If it is confirmed that there is a relatively lower salience of health risks in other countries in comparison with North America, there may be several reasons for the difference. In some countries, the roll-out of installation is not yet complete, and health concerns may grow as the roll-out progresses. Indeed, health concerns appear to be growing with the roll-out of smart meters in Australia and in the United Kingdom (see Stop Smart Meters Australia 2013, Mason 2013). Countries that pre-empt opposition with voluntary installation and opt-out provisions may mitigate opposition based on health concerns. For example, Swedish utilities allowed individuals who were electrosensitive to opt out of smart meters, and the utilities have also assisted with shielding (EI Wellspring 2011). Likewise in Germany, installation was voluntary for most consumers, and the United Kingdom has also developed opt-out provisions (Balmert *et al*. 2012, Jamieson 2013, Mason 2013). Technological differences may also play a role. In Europe, the primary technology for smart meters is 'power line communication', in contrast with the wireless technology that is commonly used in North America and Australia. Power line communication technology can also generate electromagnetic fields inside the house, and advocates and analysts concerned with health issues prefer fibre-optic cable lines and telephone lines; however, the use of wired rather than wireless technology may explain some of the differences in concerns with health effects (EI Wellspring 2013, Jamieson 2013).

If technological differences are a contributing factor, we would expect lower levels of opposition in areas of the United States with smart-meter systems based on wired technologies. For example, the EMF Safety Network lists no anti-smart-meter organisation for Idaho, where Idaho Power has adopted wired transmission. Our searches of media reports could identify only sporadic individual opposition but no organised movement equivalent to that of other states and provinces (Idaho Power 2013). With respect to privacy, the utility also collects information only four times per day, and it does not sell customer information (Idaho Power 2013) Two American cities (Fairfield, Iowa, and Chattanooga, Tennessee) are also using fibre-optic systems, which we would also expect to lead to reduced opposition.

Implication 3: Although there is evidence for a relationship between right-wing political views and opposition to smart meters among some organisations in the United States, the likely general pattern with respect to party politics is that opposition is associated with out-of-power or marginal political parties and groups. Opposition campaigns may exhibit a ‘strange bedfellows’ phenomenon; for example, opponents who attended a smart-meter protest in Los Angeles included both Tea Party (right-wing) and Occupy (left-wing) groups (Stop Smart Meters 2013). Furthermore, the comparison of the British Columbia case with the US cases is important, because in the Canadian province, the right-wing government supported smart-meter installation, and the more left-wing opposition party opposed it. In Ontario the leader of the opposition Progressive Conservative Party promised to unplug smart meters, which he described as tax machines devised by the premier of the incumbent Liberal Party (Stricker 2011). In the United States, smart meters tend to be linked to the Obama administration, and opposition is strong amongst right-wing Tea Party groups. Thus, the provisional hypothesis is that when smart-meter installations become linked to party politics, the party that is out of power may take up the issue as part of its general opposition programme.

Implication 4: When a government or utility allows an opt-out provision, opposition may dissipate somewhat, but it tends to move on to related issues. The comparative analysis shows that opt-out rates range from 1% in Maine to 4% in Vermont to 18.3% in one part of British Columbia (Skelton 2013). It is likely that some opponents will lose interest in the issue once they have opted out, because having an opt-out provision shifts the terms of the debate to a consumer choice, akin to installing a Wi-Fi system in one’s home. However, in the state of Maine, the opposition shifted to support for a no-fee opt-out provision, and it also supported a bill (LD 1456) that would require the return to electromechanical meters and would support local renewable energy (Maine Coalition to Stop Smart Meters 2013c). There is also a case in Texas where there is an effort to return to analogue meters, and in Fairfield, Iowa, the utility is shifting its water meters to fibre-optic technology. In California, there is also a focus on opt-out charges and implementation irregularities. Thus, a range of issues is emerging as the next area of opposition after opt-out provisions are obtained.

Conclusion

In addition to research implications discussed above about the factors that shape public opposition and the role of concern with health risks in the opposition, this article also has potential implications for regulators and utilities who are confronting public opposition based on health risks. Utilities view growing interest in opt-out provisions with concern, and they are devising strategies to reduce the number of customers who elect to opt out of smart-meter installation (Evans 2012). The standard policy response, shared by the industry and most government regulators, has been to:

- Dismiss health-related concerns and precautionary arguments by arguing that measurements of radio frequencies from wireless smart meters are within regulatory guidelines.
- Attempt to prevent governments from developing opt-out laws and no-fee provisions for continued use of analogue meters.
- Develop stronger communication and outreach programmes, and develop non-mandatory opt-in incentives for households that allow smart meters to communicate with thermostats and appliances to allow remote control by the utilities during peak load.

This strategy may prove successful in some regions, but it could underestimate the extent of the challenge that is emerging. Assurances to the public that there is no risk whatsoever involve a one-sided reading of an intense scientific controversy about the non-thermal health effects of electromagnetic fields, and they ignore the spillover effects from research and policy decisions on mobile phones, mobile phone masts and wireless Internet transmissions. Thus, the strategy of dismissing the science on health concerns for wireless microwaves involves entering into a scientific controversy in which there are experts with appropriate credentials who support the view that there are health risks from at least some forms and locations of wireless smart meters (see, for example, BioInitiative Working Group *et al*. 2012), and for which international bodies have begun to recognise health risks for the related area of mobile phones (International Agency for Research on Cancer 2011). Furthermore, the strategy of attempting to prevent governments from developing opt-out laws runs into conflict with powerful political frames involving household-level privacy and rights to control over residential property, and the trend is for increasing support for opt-out provisions. The opt-out provisions could mollify the most vocal opponents, but it is also possible that the number of customers who wish to opt out could grow if there are no fees and penalties; if security and privacy violations begin to emerge and receive public attention; if more customers become convinced that claims of health risks are well founded; and if customers find time-of-use incentives to be unduly burdensome and costly. Because the reasons for opposition often include a mixture of health, privacy, security and cost concerns, public opposition could continue even if education campaigns convinced the public that health concerns were not well founded.

A more proactive strategy would view the opposition to wireless smart meters not as a scientific, communication and political challenge to be surmounted but instead as a technical challenge that can be the basis of continued experimentation with system design and governance. This strategy is consistent with the one proposed by Lineweber, who has argued:

> Ultimately, the data reported here suggest that the industry needs to think about the challenge of communicating with residential customers about Smart Grid investments as less an education task (since it is not just about 'educating customers' about promised downstream benefits) and more a reassurance task (communicating to customers why they can and should trust the promises made to them by their utility on these issues). (Lineweber 2011, p. 99).

This position is also consistent with the general findings of the science and technology studies literature on the public understanding of science as essentially an issue of public trust in experts rather than public lack of knowledge (Wynne 2006). As costs decline for on-site energy generation and storage, customers who do not believe in assurances of health, security and privacy may abandon the grid for more resilient, secure and sustainable off-grid systems. An innovative approach to the design of smart meters would include the following elements:

- Experimentation with fibre-optic and telephone lines, wake-up meters (which transmit only when prompted), prepaid meters, shielding and other design changes in order to gain information about the effects of design innovations on customer acceptance, cost and security vulnerability relative to wireless and power line communication systems.
- Development of strict industry privacy standards such as the Dutch guidelines of daily reporting with an opt-in provision for more frequent intervals and an opt-in provision for sale of information to commercial third-parties.
- Exploration of other, perhaps less expensive ways to manage peak load (such as through distributed energy storage) that may not require changes in customer-oriented technology and habits.

By treating the concerns of a small but vocal mobilised public as an opportunity rather than as a threat, it would be possible construct a technological system that has a high level of public acceptance and is more resilient to future knowledge about health and other risks posed by the new technology. This approach might develop innovations that reduce long-term political conflict and also provide savings on the costs of system redesign in the future.

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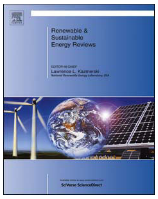

Social dimensions of smart grid: Regional analysis in Canada and the United States. Introduction to special issue of *Renewable and Sustainable Energy Reviews*

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ABSTRACT

This special issue of Sustainable and Renewable Energy Reviews is focused on the social and policy dimensions of smart grids, an emerging set of technologies and practices which have the potential to transform dramatically electricity systems around the world. The six related articles explore social and political dynamics associated with smart grid deployment in the United States of America (USA) and Canada. Aspects examined in this special issue include the evolution of smart grid policy in Ontario, media coverage of smart grid experiences in Canada and smart grid approaches being taken in Québec. Other aspects covered include an analysis of smart grid systems planning post-Superstorm Sandy (that hit the Northeastern coast of the USA in 2012), the environmental framing of socio-political acceptance of the smart grid in British Columbia, and news coverage of the smart grid in the USA and Canada. These articles were supported by collaborative research from the National Science Foundation in the USA and the Social Sciences and Humanities Research Council in Canada which involved three expert workshops held in Canada in 2013, 2014 and 2015. The six articles were accepted after a vigorous review process overseen by the guest editors of this special issue. The contents are in keeping with the aims and scope of the journal which is to bring together under one roof the current advances in the ever broadening field of renewable and sustainable energy.

1. Introduction

At the June 2016 'Three Amigos Summit' in Ottawa the leaders of the United States of America (USA), Canada and Mexico committed to generating 50% of their combined electricity from clean (non-carbon emitting) energy sources by 2025. Presently the joint non-fossil fuel electricity total stands at 37%, but with marked national differences, with approximately 20% in Mexico; 33% in the USA and 80% in Canada. It is possible to question the real level of ambition implied by this recent collective commitment [1], but there is no denying that issues of electricity system reform, cross-national energy dialogue, and climate change have been assuming ever greater importance in the North American context.

Two deep-rooted drivers point to the impending transformation of today's electricity systems. First, the continuing impact of the Information and Communications Technology (ICT) revolution is opening up possibilities for technological (but also economic, social, and cultural) innovation in key sectors including personal transportation (electric vehicles, driverless vehicles, Uber), electricity supply (solar power, renewables deployment, distributed generation, demand response, smart grids), and end use of all kinds including industry, commercial, and households. Second, the growing appreciation of climate risks is encouraging movement away from the GHG emitting generation technologies which have formed the backbone of electricity supply in most countries. Research on potential long-term low carbon development pathways suggest that meeting international climate

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Abbreviations: CCS, Carbon capture and storage; GHG, Greenhouse gas emissions; ICT, Information Communication Technology; IEA, International Energy Agency; NSF, National Science Foundation; RSER, Renewable and Sustainable Energy Reviews; SI, special issue; SSHRC, Social Science and Humanities Research Council;; USA, United States of America

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targets will require developed countries to complete decarbonization of electricity generation before mid-century, massively increase end-use efficiency, and double (or triple) electricity supply, as clean power is called upon to assume energy loads in transport, buildings, and industrial applications currently met by fossil fuels [2,3].

Thus we stand at the threshold of a potentially dramatic transition in electricity systems, that will change not just how power is produced and what it is used for, but also who produces and consumes it, and where. New technologies and societal expectations are already disrupting existing business models and regulatory arrangements [4,5]. 'Smart grids' are a critical element of the coming changes, representing both technological and social change that could facilitate renewables deployment, broaden household, community and industry engagement in energy decision-making, boost efficiency, expand demand management, enhance reliability and open up new energy services. But smart grids also serve to articulate very different views of electricity systems futures, involving more or less decentralized and distributed patterns of production, consumption, ownership and control [6,7].

Smart grids [8,9] have the potential to change how variable renewable energy and other energy vectors are integrated into the overall energy system [10,11], transforming pathways related to heating [12], transport [13–15] and cities (so-called smart cities) [16]. They may contribute to a more sustainable society, in keeping with the aims and objectives of the Paris Agreement on climate change [17]. And they may herald a more intelligent 'big data' driven society, where energy costs, carbon emissions, the economy and energy security are all interlinked as an energy quadrilemma [18,19] with complex social, economic and policy implications.

North American electricity systems are shaped by state and provincial level laws, regulations, and policies, and by utility-specific approaches and technology adoption decisions which are influencing perceptions of the value of renewable resources and shaping smart grid development [20]. Variation in state and provincial policies has influenced renewable energy development and integration in different ways which, coupled with divergent utility policies, is creating a complex and heterogeneous North American energy landscape [21]. But inter-system linkages are changing how energy grids across North America are planned, built and operated, and how citizens engage with energy issues. The bilateral links between the states and provinces in the USA and Canada are particularly important because of close interdependence.

This special issue (SI) of six articles in *Renewable and Sustainable Energy Reviews* (RSER) explores some of the social dynamics and complexity currently shaping perceptions of smart grid and renewable energy in the USA and Canada. The articles stem from collaborative research funded by the National Science Foundation (NSF) in the USA and the Social Sciences and Humanities Research Council (SSHRC) in Canada. They explore different provincial contexts (Ontario, Quebec and British Columbia), country contexts (the USA and Canada), and regional perceptions following electricity system disruption (Hurricane Sandy).

2. Social science research and energy system change

As the pace of energy system change accelerates, the need for energy-related social science is increasingly acknowledged [22–24]. While energy research has traditionally tended to focus on technological innovation and economic analysis, recognition of the importance of cultural, social, political and institutional dimensions has been growing rapidly [26,27]. Social and political factors profoundly influence energy outcomes. Consider why some countries have turned their back on nuclear power (Germany), while their neighbors continue to rely heavily on this technology (France). Or reflect upon the recent upsurge in movements to block pipeline construction in Canada and the USA. It is not engineering or economics that primarily lie behind these developments, but political and social factors. Note also how political skepticism and public opposition in many countries have torpedoed the International Energy Agency's (IEA) ambitious plans to roll out a hundred large-scale carbon capture and storage (CCS) demonstration projects, despite initial support from many governments which considered CCS deployment as an important tool to secure cost-effective climate mitigation [28]. And witness how vocal public opposition to Ontario's wind energy roll-out was spurred by poor policy design which favored large scale multinational-led deployments (that left little place for community projects) and rode rough shod over local planning institutions [29].

Social science research can contribute to the way societies address energy problems by helping identify critical questions and enhancing societal reflexivity, interrogating the interests, institutions and ideas that are at play, and identifying pathways towards more sustainable energy systems. By analyzing factors shaping policy implementation and technology deployment in practice, social scientists are able to engage in critical operational arguments that can lead to increased understandings of the complexities of energy technology innovation. Social science research employs many kinds of methodologies, examining phenomena at individual, group and broader systems level, and employing a variety of quantitative and qualitative techniques. Some of the more important contemporary energy politics- and policy-related literatures include those on innovation systems [30], societal transitions [31–33], political economy [34], and social practice [35].

3. Smart grid as a critical site of contestation

The idea of smart grid is generally associated with the application of ICT systems to transmission system design and operation, but it has come to be used more widely to refer to the overall configuration of the electricity system of the future [6,36]. Smart grids are typically presented as embodying a progressive, technologically optimistic, future that offers a portfolio of societal benefits, including increased system efficiencies, economic gains (high tech industry, jobs), and energy security or resilience, as well as empowering societies to address urgent environmental problems such as climate change [36]. But there is no *one* smart grid vision. Instead the idea covers a range of technological configurations (some already deployed or deployable, others still on the drawing boards) and many different social models for building the electricity systems of the future [36]. At one extreme, smart grids could be largely about 'micro grids' and a devolved and decentralized system of supply. On the other, they could involve a 'super grid' moving large amounts of power across continents [6]. Ownership, control and information flows could be organized in different ways, involving existing utilities, new entrants, local communities and cooperatives, or individual 'prosumers' [37].

In fact, societal debates, utility planning and investment decisions being taken today *already* privilege some patterns of smart grid transitions over others [38]. Choices relating to the ends pursed as priorities (e.g. efficiency gains, cost containment, resiliency enhancement, renewable deployment, demand management, and so on) favor particular technological configurations, and the sequencing or timing of innovation. Moreover, there is a vast gulf between the idealistic visions of an enhanced grid – that would allow electricity to do so much more for societies – and the practical experiences with smart meter deployment (the first public face of the smart grid) experienced by consumers in some areas. So 'smart grids' have emerged as a site of negotiation and contestation, where different groups of social actors (e.g. utilities, regulators, large and small consumers, technology companies, energy service providers, etc.) argue over the future of the electricity system [6,36,39,40]. And by examining these struggles it is possible to gain a critical understanding about the social and political factors influencing the evolution of electricity provision.

4. Articles in this special issue

The work presented in the articles in this SI builds on previous social science research published in this venue focusing on the complexities of assessing the value [41] and benefits of smart grids [42], smart grid experiences in particular countries [43], and end-user perceptions and acceptance of smart grid technology [44]. As *Renewable & Sustainable Energy Reviews* covers advances in sustainable energy and renewable energy technology, it is an ideal venue for analysis of the social and policy dimensions of smart grid. The journal has published extensively on the technical dimensions of smart grid [45,46], ranging from the creation of micro-grids to large-scale wind integration [47], and addressing country-specific contexts for smart grid development [43]. The six papers in this SI complement the existing publications in RSER by providing analysis of the social dimensions of smart grids in different regions of Canada and the United States.

In the first article, 'Electric (Dis) Connections: Comparative Review of Smart Grid News Coverage in the United States and Canada' [48], the authors examine press treatment of smart grids in the two countries, tracing the different patterns of smart grid engagement. The next three articles focus on the experience in different Canadian provinces, tracing the reception of smart grid related policy initiatives in Quebec, Ontario and British Columbia. 'Smart Grid Development in Quebec: A Review and Policy Approach' [49], draws on John Kingdon's analysis of 'policy streams' to explain why smart grid initiatives in that province have remained modest and 'security focused'. 'Institutional Diversity, Policy Niches and Smart Grids: A Review of the Evolution of Smart Grid Policy and Practice in Ontario, Canada' [50], highlights the more active policy engagement with smart grids in Canada's largest province, and notes the ever more important role assumed by non-traditional 'behind the meter' actors and activities. And 'The Role of Environmental Framing in Socio-political Acceptance of Smart Grid: The Case of British Columbia, Canada' [51] examines the different frames used by BC actors to structure ongoing argument about smart grids. The fifth article – 'Smart Grid Framing Through Smart Meter Coverage in the Canadian Media: Technologies Coupled with Experiences' [52] - is focused upon media coverage of smart-meter installation across Canada, assessing the different levels and character of public opposition in key regions. Finally, 'Smart Grid Electricity System Planning and Climate Disruptions: A Review of Climate and Energy Discourse Post-Superstorm Sandy' [53] compares the ways electricity system stakeholders in Massachusetts, New York and Vermont reacted in the aftermath of Superstorm Sandy, focusing on the links between energy policy and climate change, and the relative importance accorded to climate adaptation and mitigation.

Taken together, these articles allow for a rich and multi-faceted examination of how different contexts are shaping smart grid development. These contexts highlight different political priorities which are transforming energy markets, international electricity sales, and different configurations for smart grid technologies. Additionally, the papers use multiple social science methods including media analysis, focus groups, interviews and documentary analysis to explore social dimensions of smart grid development.

5. Conclusion

As the articles in this collection illustrate, new technologies are born into a dense complex of existing techno-social relations. Energy transitions involve complex struggles as new technological options and social configurations are defined, contested and redefined [54–56]. The ICT revolution and the imperative of addressing climate change are enabling disruptive innovation that opens the door to reconstruction of electricity systems to more adequately fulfill societal needs [6,36]. Increased international co-ordination (as witnessed in the United States, Canada, Mexico agreement cited at the outset of this introduction) and intra-state cooperation (consider the recent Quebec/Ontario power agreement that will bring cheap hydro from Quebec to slow electricity rate increases in Ontario and help the province meet its climate targets) are important features of this new context. But it is also true that arguments about electricity system modernization in North America are currently taking place in an uncertain economic environment, where recovery from the 2008 recession remains uneven, and concern about growing inequality is expanding including greater awareness about concentrated income gains at the top of the earnings pyramid. To this must be added the political uncertainty created by the 2016 U.S. presidential election. So it is perhaps not surprising that proposals for altering electricity provision get entangled with broader societal debates.

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Policy and society related implications of automated driving: A review of literature and directions for future research

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ABSTRACT

In this paper, the potential effects of automated driving that are relevant to policy and society are explored, findings discussed in literature about those effects are reviewed and areas for future research are identified. The structure of our review is based on the ripple effect concept, which represents the implications of automated vehicles at three different stages: first-order (traffic, travel cost, and travel choices), second-order (vehicle ownership and sharing, location choices and land use, and transport infrastructure), and third-order (energy consumption, air pollution, safety, social equity, economy, and public health). Our review shows that first-order impacts on road capacity, fuel efficiency, emissions, and accidents risk are expected to be beneficial. The magnitude of these benefits will likely increase with the level of automation and cooperation and with the penetration rate of these systems. The synergistic effects between vehicle automation, sharing, and electrification can multiply these benefits. However, studies confirm that automated vehicles can induce additional travel demand because of more and longer vehicle trips. Potential land use changes have not been included in these estimations about excessive travel demand. Other third-order benefits on safety, economy, public health and social equity still remain unclear. Therefore, the balance between the short-term benefits and long-term impacts of vehicle automation remains an open question.

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Introduction

Automated driving is considered to be one of those technologies that could signal an evolution toward a major change in (car) mobility. Estimations about the extent of this change can be inferred by answering the following two questions: (a) what are the potential changes in mobility and the implications for society associated with the introduction of automated driving and, (b) to what extent are these changes synchronized with broader concurrent societal transformations that could enhance the radical dynamic of such mobility technology? Examples of social transformations could be the digital and sharing economy, the livability and environmental awareness movement and the connectivity, networking, and personalized consumption trends.

In this paper, the focus is on the first question, aiming to (a) explore the potential effects of automated driving relevant to policy and society, (b) review findings discussed in literature about these effects, and (c) identify areas for future research. Thus far, scholarly efforts have been mainly concentrated on the technological aspects of vehicle automation (i.e. road environment perception and motion planning) and on the implications for driver and traffic flow characteristics. Accordingly, review efforts have focused on the development and operation of vehicle automation systems and the associated technologies (see Gerónimo, López, Sappa, & Graf, 2010; González, Pérez, Milanés, & Nashashibi, 2016; Piao & McDonald, 2008; Shladover, 2005; Shladover, 1995; Sun, Bebis, & Miller, 2006; Turner & Austin, 2000; Vahidi & Eskandarian, 2003; Xiao & Gao, 2010). Several review studies have also focused on the first-order impacts of vehicle automation with a special emphasis on traffic flow efficiency (see Diakaki, Papageorgiou, Papamichail, & Nikolos, 2015; Hoogendoorn, van Arem, & Hoogendoorn, 2014; Hounsell, Shrestha, Piao, & McDonald, 2009; Scarinci & Heydecker, 2014) and human factor aspects such as behavioral adaptation, driver's workload, and situation awareness (see Brookhuis, de Waard, & Janssen, 2001; de Winter, Happee, Martens, & Stanton, 2014; Stanton & Young, 1998). A partial overview of the wider implications of automated vehicles has been recently made by Fagnant and Kockelman (2015) with the aim to provide an order-of-magnitude estimation about the possible

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economic impacts of automated vehicles in the US context.

The remainder of this paper is structured as follows. Our methodology is first described (Section 2) and then a simplified concept, to represent the areas of possible policy and society related implications of automated vehicles, is presented (Section 3). In Sections 4–6 the results of our analysis about the first, second, and third order implications of automated driving are presented, respectively. Every sub-section in Sections 4–6 is structured in two parts. The first part presents the analysis about the possible implications of automated driving and their mechanisms (assumptions) and the second part is the review of the respective results found in existing literature (literature results). Section 7 presents conclusions and summarizes directions for future research.

Methodology

Our methodology involves two steps. First, a simplified concept is developed in a structured and holistic way, representing what the possible implications of automated vehicles are. Then, (a) the impacts of automated driving and their respective mechanisms, (b) existing literature results about these implications, and (c) research gaps between possible impacts and existing literature results are identified.

The impacts of automated driving and their respective mechanisms are explored, based on our own analytical thinking. Then, the literature results about the implications of automated driving are reviewed based on Scopus and Web of Science listed peer-reviewed journal articles. Included in our review were articles dated up to January 2017 containing in the title, abstract, or keywords any combination of the following keywords: advanced driver assistance system(s), [cooperative (C)] adaptive cruise control (ACC), vehicle automation, autonomous vehicle(s), autonomous car(s), self-driving vehicle(s), self-driving car(s), driverless vehicle(s), driverless car(s), automated vehicle(s), automated car(s), automated driving, robocar(s), and the keywords appearing in Table 1 for each area of implication. We primarily limited our review to peer-reviewed academic literature for two reasons: (a) the number of articles is already very high and (b) explicit review is an indication of quality. This does not mean that other literature does not have sufficient quality. Therefore, in the case of very limited or no results for specific implications of automated vehicles, our search was expanded to Google and Google Scholar, aiming to identify any unpublished reports of systematic studies. We did not include any policy reports on automated vehicles produced by governments or other institutions in our review.

Table 1. Keywords used to identify scholarly articles about the implications of automated vehicles.

Implication	Keyword
Travel cost	Cost, travel time, comfort, value of time, travel time reliability
Road capacity	Capacity, congestion, traffic flow
Travel choices	Travel choice(s), mode choice(s), travel behavior, travel distance, vehicle kilometers traveled, vehicle miles traveled, modal shift
Vehicle ownership and sharing	Vehicle ownership, car ownership, vehicle sharing, car sharing, ride sharing, shared vehicle(s)
Location choices and land use	Location choice(s), land use(s), accessibility, residential density, urban form, urban structure, urban design
Transport infrastructure	Road infrastructure(s), road planning, road design, intersection design, parking infrastructure(s), public transport service(s), transit service(s), cycle lane(s), cycle path(s), sidewalk(s), pavement(s)
Energy consumption and air pollution	Fuel, energy, emissions, pollution
Safety	Safety, accident(s), crash(es), risk, cyberattack(s)
Social equity	Social equity, social impact(s), vulnerable social group(s), social exclusion
Economy	Economy, productivity, business(es)
Public health	Public health, human health, morbidity, mortality

This paper focuses on passenger transport and employs the Society of Automotive Engineers (SAE) International (2016) taxonomy, which defines five levels of vehicle automation. In level 1 (driver assistance) and level 2 (partial driving automation), the human driver monitors the driving environment and is assisted by a driving automation system for execution of either the lateral or longitudinal motion control (level 1) or both motion controls (level 2). In level 3 (conditional driving automation), an automated driving system performs all dynamic tasks of driving (monitoring of the environment and motion control), but the human driver is expected to be available for occasional control of the vehicle. In level 4 (high driving automation) and level 5 (full driving automation) an automated driving system performs all dynamic tasks of driving, without any human intervention at any time. In level 4, the automated driving system controls the vehicle within a prescribed operational domain (e.g. high-speed freeway cruising, closed campus shuttle). In level 5, the automated driving system can operate the vehicle under all on-road conditions with no design-based restrictions.

The ripple effect of automated driving

The ripple model was used to conceptualize the sequential effects that automated driving might bring to several aspects of mobility and society (see Milakis, van Arem,

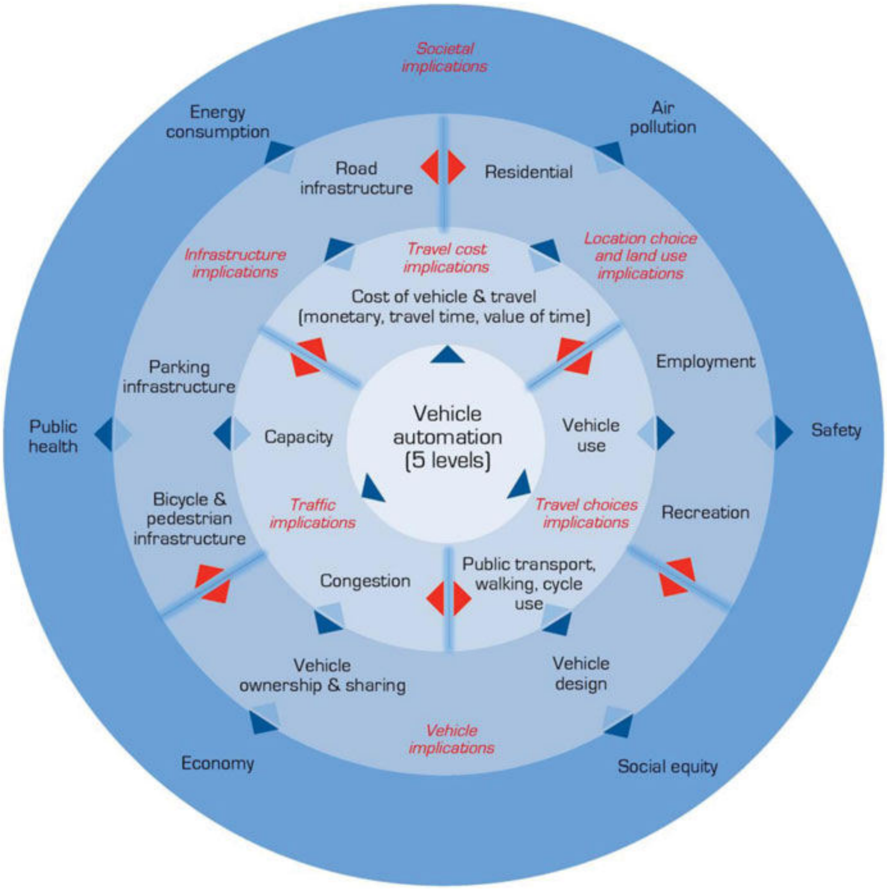

Figure 1. The ripple effect of automated driving.

& van Wee, 2015). The "ripple effect" has been widely used to describe the sequentially spreading effects of events in various fields including economics, psychology, computer science, supply chain management, and bibliometric analysis of science (see e.g. Barsade, 2002; Black, 2001; Cooper, Orford, Webster, & Jones, 2013; Frandsen & Nicolaisen, 2013; Ivanov, Sokolov, & Dolgui, 2014; Meen, 1999). The ripple model of automated driving is presented in Figure 1. Driving automation is placed in the center of the graph to reflect the source of the sequential first, second, and third order effects in the outer ripples. The first ripple comprises the implications of automated driving on traffic, travel cost, and travel choices. The second ripple includes implications of automated driving with respect to vehicle ownership and sharing, location choices and land use, and transport infrastructure. The third ripple contains the wider societal implications (i.e. energy consumption, air pollution, safety, social equity, economy, and public health) of the introduction of automated vehicles.

The ripple model of automated driving does not hold the exact same properties as the respective ripple model in physics that describes the diffusion of waves as a function of time and distance. Therefore, the ripple model of automated driving should not be taken too strictly. Feedbacks can occur in our model. For example, changes in travel cost (first ripple) might influence accessibility, then subsequently location choices, land use planning, and real estate investment decisions (second ripple), which in turn could affect travel decisions (e.g. vehicle use) and traffic (first ripple). Also, there might be no time lag between sequential effects. For example, vehicle use changes will immediately result in safety or air pollution changes. Finally, it should be clear that effects on fuel consumption, emissions and accidents risk can occur soon after the introduction of automated vehicles, yet the wider (societal) impacts on energy consumption, air pollution, and safety (third ripple) can be evaluated only after changes in the first two ripples are taken into account.

First-order implications of automated driving

In this section the first-order implications of automated driving on travel cost, road capacity, and travel choices are explored (see also Table 2 for an overview of studies on first-order implications for automated vehicles).

Travel cost

Assumptions

Potential implications for both the fixed (capital) cost of owning an automated vehicle and the generalized transport cost (GTC), which comprises effort, travel time,

Table 2. Summary of literature review results.

Possible effect of automated vehicles	Effect	Comments	Source
First-order implications			
Travel cost			
Fixed cost of automated vehicles	+	Current automated vehicle applications cost several times the price of a conventional vehicle in the US, but the price could be gradually reduced to $3000 or even lower with mass production and the technological advances of automated vehicles.	Fagnant & Kockelman, 2015
Travel comfort	?	Comfort has been incorporated in trajectory planning and ACC algorithms as the optimizing metric. Motion sickness, apparent safety and natural human-like paths could be included in path planning systems. Time headway between vehicles below 1.5–2.0 seconds can influence comfort.	Dang, Wang, Li, & Li, 2015 Elbanhawi et al., 2015; Glaser et al., 2010; Lewis-Evans et al., 2010; Li et al., 2011; Luo et al., 2015; Moon et al., 2009; Raimondi & Melluso, 2008; Siebert et al., 2014; Bellem et al., 2016; Diels & Bos, 2016; Lefèvre et al., 2016
Travel time	−	Vehicle automation can reduce delays on highways, at intersections and in contexts involving shared automated vehicles.	Arnaout & Arnaout, 2014; Dresner & Stone, 2008; Fajardo et al., 2012; Ilgin Guler et al., 2014; International Transport Forum, 2015; Kesting et al., 2008; Khondaker & Kattan, 2015; Levin et al., 2016; Li et al., 2013; Ngoduy, 2012; Yang et al., 2016; Zohdy & Rakha, 2016
Value of time	?	Automated vehicles (level 3 and higher) could reduce the value of time. Yet, value of time could increase for users of automated vehicles as egress mode to train trips. The ability to work on the move is not perceived as a major advantage of an automated vehicle.	Cyganski, Fraedrich, & Lenz, 2015; Milakis et al., 2017; Yap et al., 2016
Road capacity			
Highway capacity	+	The higher the level of automation, cooperation and penetration rate, and the higher the positive impact on road capacity. A 40% penetration rate of CACC appears to be a critical threshold for realizing significant benefits on capacity (>10%), while a 100% penetration rate of CACC could theoretically double capacity. Capacity impacts at level 3 or higher levels of vehicle automation and more advanced levels of cooperation among vehicles, but also between vehicles and infrastructure, could well exceed this theoretical threshold. Capacity might be affected by vehicle heterogeneity. Capacity could decrease in entrance/exit of automated highway systems.	Arnaout & Bowling, 2011; Arnaout & Arnaout, 2014; Delis, Nikolos, & Papageorgiou, 2015; Fernandes, Nunes, & Member, 2015; Grumert, Ma, & Tapani, 2015; Hoogendoorn, van Arem, & Hoogendoorn, 2014; Huang, Ren, & Chan, 2000; Michael, Godbole, Lygeros, & Sengupta, 1998; Monteil, Nantes, Billot, Sau, & El Faouzi, 2014; Ngoduy, 2013; Rajamani & Shladover, 2001; Shladover, Su, & Lu, 2012; van Arem, van Driel, & Visser, 2006; Yang, Liu, Sun, & Li, 2013; Carbaugh et al., 1998; Hall et al., 2001; Le Vine et al., 2015; Michael et al., 1998; Talebpour & Mahmassani, 2016; Wang et al., 2016a, b; Xie et al., 2016; Zhou et al., 2016)
Intersection capacity	+	Significant capacity benefits (more than 100%, under certain conditions) are expected from automated intersection control systems.	Clement, Taylor, & Yue, 2004 Kamal et al., 2015
Travel choices			
Vehicle miles traveled	+	Automated vehicles could induce an increase in travel demand of between 3% and 27% due to changes in destination choice (i.e. longer trips), mode choice (i.e. modal shift from public transport and walking to car), and mobility (i.e. more trips, especially from people currently experiencing travel restrictions; e.g. elderly). Shared automated vehicles could result in additional VMT because of their need to move or relocate with no one in them to serve the next traveler. Extra VMT are expected to be lower for dynamic ride-sharing systems.	Childress, Nichols, & Coe, 2015 Fagnant & Kockelman, 2014, 2015; Gucwa, 2014; International Transport Forum, 2015; Malokin et al., 2015; Correia, de, & van Arem, 2016; Fagnant & Kockelman, 2016; Lamondia et al., 2016; Levin & Boyles, 2015; Milakis et al., 2017; Vogt et al., 2015; Zmud et al., 2016
Second-order implications			
Vehicle ownership	−	Shared automated vehicles could replace from about 67% up to over 90% of conventional vehicles delivering equal mobility levels. The overall reduction of the conventional vehicle fleet could vary according to the automated mode (vehicle-sharing, ride-sharing, shared electric vehicle), the penetration rate of shared automated vehicles and the presence or absence of public transport.	Fagnant & Kockelman, 2014; International Transport Forum, 2015; Spieser et al., 2014; Boesch, Ciari, & Axhausen, 2016; Chen et al., 2016; Fagnant & Kockelman, 2016; Zhang et al., 2015
Location choices and land use	?	Automated vehicles could enhance accessibility citywide, especially in remote rural areas, triggering further urban expansion. Automated vehicles could also have a positive impact on the density of economic activity at the center of the cities. Parking demand for automated vehicles could be shifted to peripheral zones. Parking demand for shared automated vehicles can be high in city centers, if empty cruising is not allowed.	Childress et al., 2015; Zakharenko, 2016; Zhang et al., 2015

(*Continued on next page*)

Table 2. (Continued)

Possible effect of automated vehicles	Effect	Comments	Source
Transport infrastructure	−	Shared automated vehicles could significantly reduce parking space requirements up to over 90%. The overall reduction of parking spaces could vary according to the automated mode (vehicle-sharing, ride-sharing, shared electric vehicle), the penetration rate of shared automated vehicles and the presence or absence of public transport. Less wheel wander and increased capacity because of automated vehicles could accelerate pavement-rutting damage. Increase in speed of automated vehicles could compensate for such negative effect by decreasing rut depth.	Fagnant & Kockelman, 2014, 2016; International Transport Forum, 2015; Boesch et al., 2016; Chen et al., 2016; Chen et al., 2016; Spieser et al., 2014; Zhang et al., 2015
Third-order implications			
Energy consumption and air pollution			
Fuel efficiency	+	Significant fuel savings can be achieved by various longitudinal, lateral (up to 31%), and intersection control (up to 45%) algorithms and optimization systems for automated vehicles. Higher level of automation, cooperation, and penetration rate could lead to higher fuel savings.	Asadi & Vahidi, 2011; Kamal et al., 2016; Kamalanathsharma & Rakha, 2016; Khondaker & Kattan, 2015; Li et al., 2012; Luo et al., 2010; Manzie et al., 2007; Rios-torres & Malikopoulos, 2016; Vajedi & Azad, 2015; Wang et al., 2014; Wu et al., 2011; Zohdy & Rakha, 2016
Energy consumption (long term)	?	Battery electric shared automated vehicles are associated with significant energy savings (90–100%) in the long term. The energy gains are attributed to more efficient travel and electrification. Several factors could lead to increased energy use (e.g. longer travel distances and increased travel by underserved populations such as youth, disabled, and elderly). Thus, the net effect of vehicle automation on energy consumption remains uncertain.	Brown et al., 2014; Greenblatt & Saxena, 2015; Wadud et al., 2016
Emissions	−	Vehicle automation can lead to lower emissions of NOx, CO, and CO2. Higher level of automation, cooperation and penetration rates could lead to even lower emissions. Shared use of automated vehicles could further reduce emissions (VOC and CO in particular) because of lower number of times vehicles start.	Choi & Bae, 2013; Fagnant & Kockelman, 2014; Grumert et al., 2015; Ioannou & Stefanovic, 2005; Wang et al., 2015; Bose & Ioannou, 2001
Air pollution (long term)	?	Long-term impacts of battery electric shared automated vehicles are associated with up to 94% less GHG. Yet, the net effect of vehicle automation on GHG emissions remains uncertain.	Greenblatt & Saxena, 2015; Wadud et al., 2016; Fagnant & Kockelman, 2014
Safety	+	Advanced driver assistance systems and higher levels of automation (level 3 or higher) can enhance traffic safety. Behavioral adaptation, cyberattacks, maliciously controlled vehicles and software vulnerabilities can compromise traffic safety benefits. Fully automated vehicles might not deliver high safety benefits until high penetration rates of these vehicles are realized.	Dresner & Stone, 2008; Ferguson, Howard, & Likhachev, 2008; Hayashi, Isogai, Raksincharoensak, & Nagai, 2012; Hou, Edara, & Sun, 2015; Khondaker & Kattan, 2015; Kuwata et al., 2009; Lee, Choi, Yi, Shin, & Ko, 2014; K.-R. Li, Juang, & Lin, 2014; Liebner, Klanner, Baumann, Ruhhammer, & Stiller, 2013; Martinez & Canudas-de-Wit, 2007; Shim, Adireddy, & Yuan, 2012; M. Wang, Hoogendoorn, Daamen, van Arem, & Happee, 2015; Carbaugh et al., 1998; Spyropoulou, Penttinen, Karlaftis, Vaa, & Golias, 2008; Amoozadeh et al., 2015; Brookhuis et al., 2001; Gerdes et al., 2013; Gouy et al., 2014; Hoedemaeker & Brookhuis, 1998; Markvollrath et al., 2011; Petit & Shladover, 2015; Rudin-Brown & Parker, 2004; Strand et al., 2014; Xiong et al., 2012; Young & Stanton, 2007; Dixit et al., 2016; Gong et al., 2016; Naranjo et al., 2016
Social equity	?	In-vehicle technologies can have positive effects (i.e. avoiding crashes, enhancing easiness and comfort of driving, increasing place, and temporal accessibility) for elderly. Automated vehicles could induce up to 14% additional travel demand from the non-driving, elderly, and people with travel-restrictive medical conditions. Automated vehicles offer the opportunity to incorporate social justice aspects in future traffic control systems.	Harper, Hendrickson, Mangones, & Samaras, 2016; Eby et al., 2016; Mladenovic & McPherson, 2016
Economy	?	Social benefits per automated vehicle per year could reach $3900 when there's a 90% market share of automated vehicles. Jobs in the transportation and logistics sectors have a high probability of being replaced by computer automation within the next two decades.	Fagnant & Kockelman, 2015; Frey & Osborne, 2017
Public health	?	No systematic studies were found about the implications of automated vehicles for public health.	

Note. Effects are described with the following symbols: '+': positive/increase, '−': negative/decrease, '?': uncertain/limited evidence and financial costs of a trip, are explored. The fixed costs of automated vehicles will very likely be higher than for conventional vehicles due to the advanced hardware and software technology involved. The increased fixed cost could influence the penetration rate and subsequently the magnitude of the effects of automated vehicles. The GTC, on the other hand, is expected to decrease because of lower effort, time, and money needed to travel. First, more travel comfort, enhanced travel safety, higher travel time reliability, and the possibility to perform activities other than driving (like working, meeting, eating, or sleeping) while on the move will likely lead to lower values of time. Second, less congestion delays because of increased road capacity and reduced (or even eliminated) search time for parking owing to self-parking capability, but also increased use of shared vehicles, would possibly require less travel time. Third, enhanced efficiency of traffic flow along with more fuel-efficient vehicles because of their lighter design (owing to less risk of having an accident) could also reduce the monetary cost of travel. Due to shorter headways, air resistance will possibly decrease, further reducing fuel use and costs. However, potential increase of vehicle travel demand because of enhanced road capacity, reduced GTC, and/or proliferation of vehicle sharing systems and urban expansion in the longer term, could compromise travel time and cost savings. The counter effects of increased vehicle demand could include increased congestion delays, longer trips, and more fuel costs.

Literature results

Fagnant and Kockelman (2015) report estimations that current automated vehicle applications cost several times the price of a conventional vehicle in the US. However, they estimate that this difference in cost could be gradually reduced to $3000 or even lower with mass production and the technological advances of automated vehicles. Looking at the components of GTC, several studies have incorporated comfort in terms of longitudinal and lateral acceleration as the optimizing metric in their trajectory-planning algorithms (see e.g. Glaser, Vanholme, Mammar, Gruyer, & Nouvelière, 2010; Raimondi & Melluso, 2008). Moreover, multi-objective ACC algorithms usually incorporate ride comfort (measured in terms of vehicle acceleration) along with safety and fuel consumption as system constraints (see e.g. Dang, Wang, Li, & Li, 2015; Li, Li, Rajamani, & Wang, 2011; Luo, Chen, Zhang, & Li, 2015; Moon, Moon, & Yi, 2009). Bellem, Schönenberg, Krems, and Schrauf (2016) suggested several maneuver-specific metrics such as acceleration, jerk, quickness, and headway distance to assess comfort of automated driving style. However, Elbanhawi, Simic, and Jazar (2015) argue in their review paper that several factors of human comfort are largely ignored in research for autonomous path planning systems [i.e. motion sickness, see also Diels & Bos, 2016; apparent safety (the feeling of safe operation of the automated vehicle); natural, human-like paths]. A more recent study (Lefèvre, Carvalho, & Borrelli, 2016) developed a learning-based approach for automated vehicles with the aim to replicate human-like driving styles (i.e. velocity control). Moreover, research has shown that comfort is not only influenced by vehicle acceleration but also by the time headway when the driver is still in the loop. Both Lewis-Evans, De Waard, and Brookhuis (2010) and Siebert, Oehl, and Pfister (2014) identified in driver simulator experiments a critical threshold for time headway in the area of 1.5–2.0 seconds below which a driver's perception of comfort reduces significantly.

Limited evidence exists on the impacts of automated vehicles on the travellers' value of time. Yap, Correia, and van Arem (2016) found a higher value of time for using fully automated (level 5) compared to manually driven vehicles as egress mode of train trips in a stated preference survey in the Netherlands. These researchers attributed this result to the possible uncomfortable feeling of travelers with the idea of riding an automated vehicle, the lack of any real-life experience with automated vehicles, and the fact that an egress trip is typically a short trip not allowing the travelers to fully experience potential benefits of automated vehicles such as travel safety. Cyganski et al., (2015) reported that only a minor percentage of the respondents in their questionnaire survey in Germany declared as an advantage the ability to work on the move in an automated vehicle (level 3 and higher). On the contrary, most respondents agreed that activities that they usually undertake while driving conventional vehicles (e.g. gazing, conversing, or listening to music) would continue to be important when riding an automated vehicle. Respondents working in their current commute were found to be more likely to wish to work in an automated vehicle as well. Milakis, Snelder, van Arem, van Wee, and Correia (2017) reported a possible decrease of the value of time between 1% and 31% for users of automated vehicles (level 3 and higher) in various scenarios of development of automated vehicles in the Netherlands.

Several studies have reported results about travel time and fuel savings based on simulation of various control algorithms for automated car-following scenarios and automated intersection management. Studies about fuel savings are presented later in this article. Considering travel time, Arnaout and Arnaout (2014) simulated a four-lane highway involving several scenarios of penetration rates for cars equipped with CACC and a fixed percentage for trucks (10%). They found that travel time decreased substantially with the increase of CACC penetration rate. Ngoduy (2012) reported that a 30% penetration rate of ACC could significantly reduce oscillation waves and stabilize traffic near a bottleneck, thus reducing travel time by up to 35%. Kesting, Treiber, Schönhof, and Helbing (2008) identified travel time improvements even with relatively low ACC penetration rates. Also, Khondaker and Kattan (2015) showed that their proposed variable speed limit control algorithm could reduce travel time by up to 20% in a context of connected vehicles compared to an uncontrolled scenario. However, travel time improvements were lower when a 50% penetration rate of connected vehicles was simulated. Zohdy and Rakha (2016) developed an intersection controller that optimizes the movement of vehicles equipped with CACC. Their simulation results showed that the average intersection delay in their system (assuming 100% market penetration of fully automated vehicles, level 4 or 5) was significantly lower compared to the traffic signal and all-way-stop control scenarios. Similarly, Dresner and Stone (2008) proposed a multi-agent, reservation-based control system for efficient management of fully automated vehicles (level 4 or 5) in intersections that could widely outperform current control systems like traffic lights and stop signs. According to these researchers, this system could offer near-to optimal delays (up to 0.35 seconds); about ten times lower than the delays observed in conventional control systems. The efficiency of reservation-based intersection controls in reducing delays was also demonstrated by Fajardo, Au, Waller, Stone, and Yang (2012), Li, Chitturi, Zheng, Bill, and Noyce (2013) and Levin, Fritz, and Boyles (2016). Yet, Levin, Boyles, and Patel (2016) indicated some cases that optimized signals can outperform reservation-based intersection controls (e.g. in local road-arterial intersections) and thus, these researchers recommended a network-based analysis before any decision about replacement of traffic signals is taken. Ilgin Guler, Menendez, and Meier (2014) assumed that only a portion of the vehicles were equipped with their intersection control algorithm and tested the impacts on delays for two one-way-streets. Their simulations revealed a decrease by up to 60% in the average delay per car when the penetration rate of the control system-equipped vehicles increased by up to 60%. These researchers reported further decrease of the delays by an improved version of their intersection controller (Yang, Guler, & Menendez, 2016). Chen, Bell, and Bogenberger (2010) proposed a navigation algorithm for automated vehicles that accounts not only for travel time but also for travel time reliability. Thus, this algorithm can search for the most reliable path within certain travel time constraints using either dynamic or no traffic information. Finally, when considering the impacts of shared automated vehicles on travel time, the International Transport Forum (2015) reported a reduction of up to 37.9% compared to the current travel time of private cars in Lisbon, Portugal, based on a simulation study.

Road capacity

Assumptions

Automated vehicles could have a positive influence on free flow capacity, the distribution of vehicles across lanes and traffic flow stability by providing recommendations (or even determining in level 3 or higher levels of automation) about time gaps, speed and lane changes. Enhanced free flow capacity and decreased capacity drops (i.e. fewer episodes of reduced queue discharge rate) could increase the road capacity and thus reduce congestion delays. Nevertheless, benefits in traffic flow efficiency will very likely be highly dependent on the level of automation, the connectivity between vehicles and their respective penetration rates, the deployment path (e.g. dedicated lanes versus integrated, mixed traffic) as well as human factors (i.e. behavioral adaptation). Moreover, increased vehicle travel demand could have a negative impact on road capacity owing to more congestion delays and subsequently increased capacity drops. Thus, although the benefits of automated vehicles in the short term are expected to be important, the long-term implications are uncertain and highly dependent on the evolution of vehicle travel demand.

Literature results

Hoogendoorn, van Arem, and Hoogendoorn (2014) concluded in their review study that automated driving might be able to reduce congestion by 50%, while this reduction could go even higher with the help of vehicle-to-vehicle and vehicle-to-infrastructure communication. Several studies have explored the traffic impacts of longitudinal automation (i.e. ACC and CACC), based on simulations. Results suggest that ACC can only have a slight impact on capacity (Arnaout & Arnaout, 2014). CACC, on the other hand, showed positive impacts on capacity (van Arem, van Driel, & Visser, 2006) but these will probably only be important (e.g. >10%) if relatively high penetration rates are realized (>40%) (Arnaout & Bowling, 2011; Shladover, Su, & Lu, 2012). A 100% penetration rate of CACC could theoretically result in double capacity compared to a scenario of all manually driven vehicles (Shladover et al., 2012). Ngoduy (2013) and Delis, Nikolos, and Papageorgiou (2015) have also confirmed that CACC performs better than ACC with respect to both traffic stability and capacity.

Several other studies have confirmed the beneficial effects of different types and levels of vehicle automation and cooperation on capacity in various traffic scenarios (see e.g. Talebpour & Mahmassani, 2016). In particular, Fernandes, Nunes, and Member (2015) proposed an algorithm for positioning and the cooperative behavior of multiplatooning leaders in dedicated lanes. Their simulations showed that the proposed platooning system can achieve high traffic capacity (up to 7200 vehicles/hour) and outperform bus and light rail in terms of capacity and travel time. Huang, Ren, and Chan (2000) designed a controller for automated vehicles that requires information only from vehicle sensors. Their simulations in mixed traffic conditions that involved both automated and human controlled vehicles showed that peak flow could reach 5000 vehicles/hour when 70% of the vehicles are automated. Moreover, Michael, Godbole, Lygeros, and Sengupta (1998) showed, via the simulation of a single lane automated highway system, that capacity increases as the level of cooperation between vehicles and platoon length increases. Several other studies have not only reported enhanced traffic flow efficiency because of cooperation and exchange of information between vehicles (e.g. Monteil, Nantes, Billot, Sau, & El Faouzi, 2014; Wang, Daamen, Hoogendoorn, & van Arem, 2016b; Xie, Zhang, Gartner, & Arsava, 2016; Yang, Liu, Sun, & Li, 2013; Zhou, Qu, & Jin, 2016) but also between vehicles and infrastructure (e.g. variable speed limits, see Grumert, Ma, & Tapani, 2015; Wang, Daamen, Hoogendoorn, & van Arem, 2016a). Rajamani and Shladover (2001) compared the performance of autonomous control systems and cooperative longitudinal control systems (with and without inter vehicle communication respectively). These researchers showed analytically that the autonomous control system could indeed deliver capacity benefits reaching a theoretical maximum traffic flow of 3000 vehicles/hour. However, a cooperative system comprising 10-vehicle platoons with a distance between the vehicles of 6.5 m was far more efficient, achieving a theoretical traffic flow of 6400 vehicle/hour. Theoretical traffic flow of the cooperative system could increase to 8400 vehicles/hour if the distance between the vehicles in the platoons was further reduced to 2 m.

Another group of studies identify significant capacity benefits from using automated intersection control systems. Clement, Taylor, and Yue (2004) proposed one of these conceptual systems whereby vehicles can move in closely spaced platoons when the lights turn to green at signalized intersections. These researchers showed analytically that this system could increase throughput by 163% compared to current road intersections even when they used quite conservative values for vehicle spacing in the platoons (i.e. 7.2 m). Kamal, Imura, Hayakawa, Ohata, and Aihara (2015) developed a control system which coordinates connected vehicles so they can safely and smoothly cross an intersection with no traffic lights. Both their estimations and simulations showed an almost 100% increase in capacity compared to the performance of a traditional signalized intersection. It should be noted that both Clement, Taylor, and Yue (2004) and Kamal, Imura, Hayakawa, Ohata, and Aihara (2015) assumed in their studies 100% market penetration of fully automated vehicles (level 4 or 5), no other road users (bicyclists or pedestrians), and perfect control performance (no errors).

However, some studies have identified possible trade-offs between increases in capacity and various aspects of automated vehicles. Le Vine, Zolfaghari, and Polak (2015) identified a possible trade-off between comfort level and intersection capacity. These researchers showed that if the passengers of automated vehicles were to enjoy comfort levels similar to light rail or high-speed rail (in terms of longitudinal and lateral acceleration/deceleration), intersection capacity reduction could reach 53% and delays could increase by up to 1924%. Van den Berg and Verhoef (2016) showed that automated vehicles could have both positive and negative externalities through increases in capacity and parallel decreases in the value of time, although net positive externalities seem more likely according to their analysis. Moreover, Carbaugh, Godbole, and Sengupta (1998) showed that the probability of rear-end crashes in automated highway system platoons (level 4) increases as capacity increases, especially when intra-platoon spacing becomes very small (e.g. 1 m). Yet, collision severity tends to decrease because speed differences associated with crashes become smaller in higher capacity. The results of this study refer to the first rear-end crash between two vehicles and not to secondary crashes in a platoon of vehicles. Also, Hall, Nowroozi, and Tsao (2001) pointed to possible capacity reductions in entrance/exit of automated highway systems relative to the ideal 'pipeline' capacity without any entrances or exits, while Michael, Godbole, Lygeros, and Sengupta (1998) showed that capacity in automated highway systems could decrease compared with passengers cars, when trucks and buses are added.

Travel choices

Assumptions

In the short term, the increase of road capacity, the subsequent congestion relief and the decrease in GTC could lead to an increase of vehicle travel demand. However, vehicle travel demand might also increase because of transfers, pick-ups, drop-offs, and repositions of ride-sharing and vehicle-sharing vehicles. Moreover, the decrease of GTC could enhance the accessibility of more distant locations, thus allowing people to choose such destinations to live, work, shop, recreate, and subsequently increase the amount of their daily vehicle use. The increase in vehicle use might also be the result of a modal shift from conventional public transport. For example, buses could be gradually replaced by more flexible, less costly, and easier to operate automated ride-sharing and vehicle-sharing services. The use of high capacity public transport systems, such as trains, metro, and light rail might also drop after the introduction of automated vehicles, if ride-sharing or vehicle-sharing could adequately serve high-demand corridors. Finally, the increase of ride-sharing and vehicle-sharing systems might negatively influence the use of active modes, since automated shared vehicles could effectively serve short distance trips or feeder trips to public transportation. Also, further diffusion of the activities across the city might deter walking and bicycle use. However, the possibility that people still prefer active modes for short and medium distances for exercise and health reasons or simply because they like cycling or because cycling is cheaper, cannot be excluded. Moreover, enhanced road safety might also improve (the perception of) the safety of bicycling and subsequently positively influence cycle use, especially among the more vulnerable cycling groups (e.g. the elderly, children, and women; see Xing, Handy, & Mokhtarian, 2010; Milakis, 2015).

Literature results

Fagnant and Kockelman (2015) estimated a 26% increase of system-wide vehicle miles traveled (VMT) using a 90% market penetration rate of automated vehicles. This estimation was based on a comparison with induced travel demand caused by enhancement of road capacity after the expansion of road infrastructures. Milakis et al. (2017) reported a possible VMT increase between 3% and 27% for various scenarios of development of automated vehicles in the Netherlands. Higher VMT levels because of automated vehicles were identified by Vogt, Wang, Gregor, and Bettinardi (2015) through a fuzzy cognitive mapping approach that accounted for interactions among several factors including emerging mobility concepts (e.g. demand responsive services and intelligent infrastructure). Also, Gucwa (2014) reported an increase in VMT between 4% and 8% using different scenarios of road capacity and value of time changes through the introduction of automated vehicles. His scenario simulations in the San Francisco Bay area involved increases in road capacity of between 10% and 100% and decreases in value of time to the level of a high quality train or to half the current (in-vehicle) value of time. In the extreme scenario of zero time cost for traveling in an automated vehicle the increase of VMT was 14.5%. Additional vehicle travel demand in this study was due to changes in destination and mode choices. Correia, and van Arem (2016) reported an increase of 17% in VMT after replacing all private conventional vehicles by automated ones in simulations of the city of Delft, The Netherlands. Increase in VMT was the result of more automated vehicle trips either occupied (shifted from public transport) or unoccupied (moving vehicles to find parking places with lower cost). Another study showed that a modal shift of up to 1%, mainly from local public transport (bus, light rail, subway) and bicycle, to drive-alone and shared-ride modes could be possible because of the ability to multitask in automated vehicles (Malokin, Circella, & Mokhtarian, 2015). Levin and Boyles (2015) confirmed the possibility of increased modal shift from public transport to automated vehicles especially when these vehicles become widely available to travellers with lower value of time. Lamondia, Fagnant, Qu, Barrett, and Kockelman (2016) focused on possible modal shift from personal vehicles and airlines to automated vehicles for long distance travel using Michigan State as case study. These researchers found a modal shift of up to 36.7% and 34.9% from personal vehicles and airlines respectively to automated vehicles for trips less than 500 miles. For trips longer than 500 miles, automated vehicles appeared to draw mainly from personal vehicles (at a rate of about 20%) and much less from airlines. Childress, Nichols, and Coe (2015) used the Seattle region's activity-based travel model to explore the impacts of automated vehicles on travel demand. They simulated four different scenarios with respect to the AV penetration rate and changes in capacity, value of time, parking and operation costs. They concluded that an increase of VMT between 4% and 20% is likely in the first three scenarios that assumed capacity increases of 30%. Additional VMT was the result of both more and longer trips and also because of a modal shift from public transport and walking to car. Congestion delays appeared in only one of the first three scenarios that assumed a universal decline of value of time by 35% along with reduced parking costs. In the other two scenarios (with no or limited impact on the value of time), capacity increases offset additional travel demand, offering higher network speeds. In the fourth and final scenario, a shared autonomous vehicles-based transportation system with users bearing all costs of driving was assumed. Simulation results in this case showed that VMT could be reduced by 35% with less congestion delays. Significantly higher user costs per mile (up to about 11 times) induced shorter trip lengths, lower single-occupant vehicle share and an increase of public transport use and walking by 140% and 50%, respectively.

Fagnant and Kockelman (2014), on the other hand, indicated in their agent-based simulation study that automated vehicle-sharing schemes could result in 10% more VMT compared to conventional vehicles. The reason is that shared automated vehicles will need to move or relocate with no one in them to serve the next traveler. Yet, extra VMT was found to be around 4.5% when dynamic ride-sharing services were included in the simulation

(Fagnant & Kockelman, 2016). Extra VMT was even lower when the ride-matching parameter (i.e. max time from initial request to final drop off at destination) for ride sharing travelers was increased. Also, in their simulation study for Lisbon, Portugal, the International Transport Forum (2015) reported an increase in VMT over the course of a day that could vary between 6.4% and 90.9% depending on the mode (vehicle-sharing or ride-sharing automated vehicles), the penetration rate, and the availability of high-capacity public transport. It should be noted that these studies did not take into account any potential changes in travel demand because of the introduction of automated vehicles. For example, Harper, Hendrickson, Mangones, and Samaras (2016) estimated that light-duty VMT could increase by up to 14% in the US, only through the additional travel demand of the non-driving, elderly, and people with travel-restrictive medical conditions because of automated vehicles.

Finally, Zmud, Sener, and Wagner (2016) explored impacts of automated vehicles on travel behavior using face-to-face interviews with 44 respondents from Austin, Texas. Contrary to the above modeling estimates, most of the participants (66%) stated that their annual VMT would remain the same if they would use an automated vehicle, because they would not change their routines, routes, activities, or housing location. Twenty-five percent of the participants responded that they would increase their annual VMT adding more long-distance, leisure, and local trips to their existing travel patterns.

Second-order implications of automated driving

In this section the second-order implications of automated driving for vehicle ownership and sharing, location choices and land use, and transport infrastructure are explored (see also Table 2 for an overview of studies on second-order implications of automated vehicles).

Vehicle ownership and sharing

Assumptions

The introduction of automated vehicles could facilitate the development of ride-sharing and vehicle-sharing services. Automated vehicles could significantly reduce operational costs (e.g. no driver costs) for ride-sharing and vehicle-sharing services. Such schemes could effectively meet individuals' travel demand needs with lower cost and higher flexibility compared to what today's bus and taxi systems offer to passengers. Subsequently, urban residents could decide to reduce the number of cars they own or even live car-free, avoiding the fixed costs associated with car ownership as well. However, shared automated vehicles might be utilized more intensively (e.g. additional travel to access travellers or to relocate) than conventional cars. We may thus expect shared automated vehicles to wear out faster and to be replaced more frequently.

Literature results

Several studies have simulated transport systems to explore the possibility of automated vehicles substituting conventional vehicles. Fagnant and Kockelman (2014; 2016) simulated the operation of shared automated vehicles (automated vehicles offering vehicle-sharing and dynamic ride-sharing services) in an idealized mid-size grid-based urban area and in Austin, Texas' coded network. These researchers reported that each shared automated vehicle could replace around eleven conventional vehicles. This rate dropped to around nine in a scenario of significantly increased peak hour demand. Also, Zhang, Guhathakurta, Fang, and Zhang (2015) and Boesch, Ciari, and Axhausen (2016) indicated in hypothetical and real city simulations (Zurich, Switzerland) that every shared automated vehicle could replace around ten and fourteen conventional vehicles, respectively. However, according to Chen, Kockelman, and Hanna (2016) if vehicle charging is also taken into account in the case of shared, electric, automated vehicles then the replacement rate of privately owned vehicles drops between 3.7 and 6.8. The International Transport Forum (2015) simulated different scenarios of automated modes (automated vehicles for ride-sharing and vehicle-sharing services), penetration rates, and availability of high-capacity public transport. This report indicated that shared automated vehicles could replace all conventional vehicles, delivering equal mobility levels with up to 89.6% (65% at peak-hours) less vehicles in the streets (scenario of automated ride-sharing services with high capacity public transport). Another conclusion of this study is that less automated ride-sharing than vehicle-sharing vehicles could replace all conventional vehicles. The reductions in fleet size were much lower (varying between 18% and 21.8%) when the penetration rate of shared automated vehicles was assumed at a 50% level and high-capacity public transport was also available. Finally, Spieser et al. (2014) estimated that only one third of the total number of passenger vehicles would be needed to meet travel demand needs if all modes of personal transportation vehicles were replaced by shared automated vehicles (automated vehicles offering vehicle-sharing services). These researchers used analytical techniques and actual transportation data in the case of Singapore for their study.

Location choices and land use

Assumptions

Automated vehicles could have an impact on both the macro (regional) and micro (local) spatial scale. At regional level, automated vehicles could enhance accessibility by affecting its transportation, individual and temporal components (see Geurs & van Wee, 2004 for an analysis of the accessibility components). Less travel effort, travel time, and cost and thus lower GTC could have an impact on the transportation component of accessibility. People without access to a car (not owning a car or not being able to drive) may travel to activities using (shared) automated vehicles, thus influencing the individual component of accessibility. Moreover, (fully) automated vehicles could perform certain activities themselves (e.g. pick up the children from school or the groceries from the supermarket). This could overcome any constraints resulting from the temporal availability of opportunities (e.g. stores opening/closing times) and individuals' available time. Enhanced regional accessibility might allow people to compensate lower travel costs with living, working, shopping, or recreating further away. Thus, an ex-urbanization wave to rural areas of former inner city and suburban residents could be possible, subject to land availability and land use policies. Enhanced accessibility may also affect the development of new centers. For example, former suburban employment centers could evolve into significant peripheral growth poles, serving the increased demand for employment and consumption of new ex-urban residents. The possibility to eliminate extensive parking lots in these kinds of centers because of the self-parking capability of (fully) automated vehicles could further enhance the potential of mixed-use growth in these areas. At the local level, automated vehicles could trigger changes in streetscape, building landscape design and land uses. First, the capability of self-parking and the opportunity of increased vehicle-sharing services because of automated vehicles could reduce demand for on-street and off-street parking, respectively. Subsequently, parking lanes could be converted into high occupancy vehicle lanes, bus lanes, and cycle lanes or to new public spaces (e.g. green spaces or wider sidewalks). A reduction of off-street parking requirements could bring changes in land use (infill residential or commercial development) and in building design (i.e. access lanes, landscaping). Moreover, surface parking lots and multi-story parking garages in central areas could be significantly reduced, enhancing infill development potential for people-friendly land use.

Literature results

Childress et al. (2015) identified potential changes in households' accessibility patterns in Seattle, WA, in a scenario where the transportation system of this region is entirely based on automated vehicles. This scenario not only assumed that driving is easier and more enjoyable (increased capacity by 30% and decreased value of time by 35%), but also cheaper because of lower parking costs. An analysis was performed on an activity-based model for a typical household type, using aggregate logsums to measure accessibility changes compared to a 2010 baseline scenario. Results showed that the perceived accessibility was universally enhanced across the whole region. The highest increase in accessibility was observed for households living in more remote rural areas. Changes to accessibility were also associated with an average increase of 20% in total VMT. The increase in travel demand was far higher (up to 30.6%) in outlying areas. Zakharenko (2016) analyzed the effects of fully automated vehicles on urban form from an urban economics perspective. This researcher developed a model of a monocentric two-dimensional city of half-circular shape that was calibrated to a representative US city. He assumed that workers could choose among no commute, traditional vehicle commuting and commuting by an automated vehicle taking into account variable, parking and fixed costs of each choice. According to the results, about 97% of the daily parking demand would be shifted to a "dedicated parking zone" in the periphery of the city center. This in turn would have a positive impact on the density of economic activity at the center of the city driving land rents 34% higher. On the other hand, reduced transportation costs because of automated vehicles would cause the city to expand and land rents to decline about 40% outside the city center. Finally, Zhang et al. (2015) showed in their agent-based simulation of a hypothetical city that the longer the empty cruising of shared automated vehicles the more evenly distributed the parking demand of these vehicles would be throughout the study area. If no empty cruising is allowed then parking demand of shared automated vehicles tended to be concentrated in the center of the study area.

Transport infrastructure

Assumptions

Increased road capacity because of automated vehicles could reduce future needs for new roads. However, induced travel demand resulting from enhanced road capacity, reduced GTC, and/or the proliferation of vehicle sharing systems and urban expansion may reduce or even cancel out or more than offset initial road capacity benefits. In the last case (more than offset), additional road capacity may be required to accommodate new travel demand. Automated vehicles will also be likely to reduce demand for parking, thus, probably, fewer parking infrastructures—either on-street or off-street—will be required. Moreover, a reduced need for public transport services in some areas (especially those with low and medium densities) could also lead to public transport service cuts. Pedestrians and cyclists could benefit from more space after the introduction of automated vehicles as a result of road capacity improvements. Finally, changes in ownership, organizational structure and operation of transport infrastructures might appear when fully automated vehicles (level 4 or 5) increase considerably their share in the vehicle fleet. According to Van Arem and Smits (1997) these changes could include a segmentation of the road network, operation and maintenance by private organizations and the emergence of transportation providers that could guarantee trip quality, regardless of the travel mode.

Literature results

International Transport Forum (2015) reported that both on-street and off-street parking spaces could be significantly reduced (between 84% and 94%) in all simulated scenarios that assumed a 100% shared automated vehicle fleet in the city of Lisbon, Portugal. Yet, the reduction was only incremental or even non-existent when these researchers tested scenarios with a 50% mix between shared automated and conventional vehicles. Also, Chen, Balieu, and Kringos (2016), Boesch, Ciari, and Axhausen (2016) Fagnant and Kockelman (2014, 2016), Zhang et al. (2015) and Spieser et al. (2014) offered estimations about a replacement rate of conventional vehicles by shared automated vehicles that varies between three and fourteen. Thus, parking demand could be reduced from about 67% up to over 90%.

Concerning the impact of automated vehicles on the long-term service performance of road infrastructures, Chen, Balieu, and Kringos (2016) showed that less wheel wander and increased capacity could accelerate pavement rutting damage, but potential increase in speed of automated vehicles could compensate for such negative effect by decreasing rut depth.

Third-order implications of automated driving

In this section the third-order implications of automated driving on energy consumption and air pollution, safety, social equity, economy, and public health are explored (see also Table 2 for an overview of studies on third-order implications of automated vehicles).

Energy consumption and air pollution

Assumptions

The introduction of automated vehicles might result in energy and emission benefits because of reduced congestion, more homogeneous traffic flows, reduced air resistance due to shorter headways, lighter vehicles (a result of enhanced safety), and less idling (a result of less congestion delays). Also, automated vehicles may require less powerful engines because high speeds and very rapid acceleration will not be needed for a large share of the fleet (e.g. shared automated vehicles). This could further improve the fuel efficiency and limit emissions. Yet, privately owned automated vehicles could still offer the possibility of mimicking different human driving styles (e.g. fast, slow, and aggressive). Moreover, the possibility that automated vehicles will be larger than conventional vehicles, serving passengers' needs to perform various activities while on the move, cannot be excluded. For example, extra space might be needed to facilitate office-like work (table and docking stations), face-to-face discussions (meeting table) or sleeping, and relaxing (couch, bed). Larger vehicles may limit fuel efficiency gains in this case. Shorter search time for parking and reduced needs for construction and maintenance of parking infrastructures can also lead to environmental benefits. However, shared automated vehicles may be programmed to drive continuously until the next call rather than try to find parking in a downtown area, generating more emissions. Additionally, an automated vehicle may be programmed to drive itself outside of the downtown center to an area where parking is cheaper or free, thus consuming more energy, producing more emissions and creating more traffic congestion. Finally, a smaller fleet size could be associated with lower energy and emissions for car manufacturing and road infrastructure development. Nevertheless, the potential environmental benefits of automated vehicles could be significantly mitigated by increased travel demand in the long term.

Literature results

Several studies have reported fuel savings from vehicle automation systems. Wu, Zhao, and Ou (2011) demonstrated a fuel economy optimization system that provides human drivers or automated systems with advice about optimal acceleration/deceleration values, taking into account vehicle speed and acceleration, but also current speed limit, headway spacing, traffic lights, and signs. Their driving simulator experiment in urban conditions with signalized intersections revealed a decrease in fuel consumption of up to 31% for the drivers who used the system. Khondaker and Kattan (2015) reported fuel savings of up to 16% for their proposed variable speed limit control algorithm compared with an uncontrolled scenario. Their control system incorporated real-time information about individual driver behavior (i.e. acceleration/deceleration and level of compliance with the set speed limit) in a context of 100% connected vehicles. Yet, fuel savings were lower when the penetration rate of connected vehicles was assumed at a 50% level. Also, Li, Peng, Li, and Wang (2012) showed that the application of a Pulse-and-Gliding (PnG) controller could result in fuel savings of up to 20% compared to a linear quadratic

(LQ)-based controller in automated car-following scenarios. Other studies have also reported significant fuel consumption savings in field and simulation tests of their ACC and CACC control algorithms (see e.g. Eben Li, Li, & Wang, 2013; Kamal, Taguchi, & Yoshimura, 2016; Luo, Liu, Li, & Wang, 2010; Rios-torres & Malikopoulos, 2016; Wang, Hoogendoorn, Daamen, & van Arem, 2014) including controllers for hybrid electric vehicles (Luo, Chen, Zhang, & Li, 2015; Vajedi & Azad, 2015)

In a context where there are intersections, the controller proposed by Zohdy and Rakha (2016) provides advice about the optimum course of vehicles equipped with CACC. These researchers reported fuel savings of, on average, 33%, 45%, and 11% for their system compared with the conventional intersection control approaches of a traffic signal, all-way-stop, and roundabout, respectively. Moreover, Ala, Yang, and Rakha (2016), Kamalanathsharma and Rakha (2016) and Asadi and Vahidi (2011) reported fuel savings up to 19%, 30%, and 47%, respectively, for their cooperative adaptive cruise controller that uses vehicle-to-infrastructure (traffic signal in this case) communication to optimize a vehicle's trajectory in the vicinity of signalized intersections. Finally, Manzie, Watson, and Halgamuge (2007) showed that vehicles exchanging traffic flow information through sensors and inter-vehicle communication could achieve the same (i.e. 15–25%) or even more (i.e. up to 33%, depending on the amount of traffic information they can process) reductions in fuel consumption compared to hybrid-electric vehicles.

Looking at the implications of vehicle automation for air pollution, Grumert et al. (2015) reported a reduction in NOx and Hydrocarbon (HC) emissions from the application of a cooperative variable speed limit system that uses infrastructure-to-vehicle communication to attach individualized speed limits to each vehicle. Emissions were found to decrease with higher penetration rates with this system. Wang, Chen, Ouyang, and Li (2015) also found that a higher penetration rate of intelligent vehicles (i.e. vehicles equipped with their proposed longitudinal controller) in a congested platoon was associated with lower emissions of NOx. Moreover, Bose and Ioannou (2001) found, through using simulation and field experiments, that emissions could be reduced from 1.5% (NOx) to 60.6% (CO and CO_2) during rapid acceleration transients with the presence of 10% ACC equipped vehicles. Choi and Bae (2013) compared CO_2 emissions for lane changing of connected and manual vehicles. They found that connected vehicles can emit up to 7.1% less CO_2 through changing from a faster to a slower lane and up to 11.8% less CO_2 through changing from a slower to a faster lane. Environmental benefits from the smooth reaction of ACC vehicles in traffic disturbances caused by high-acceleration maneuvers, lane cut-ins, and lane exiting were also confirmed by Ioannou and Stefanovic (2005).

In a larger scale agent-based study, Fagnant and Kockelman (2014) simulated a scenario of a mid-sized city where about 3.5% of the trips in day are served by shared automated vehicles. These researchers reported that environmental benefits of shared automated vehicles could be very important in all of the pollutant indicators examined (i.e. SO_2, CO, NOx, Volatile organic compounds [VOC] PM_{10}, and GHG [Greenhouse gas]). VOC and CO showed the highest reductions, mainly because of the significantly less number of times a vehicle starts, while the impact on Particulate matter with effective diameter under 10 µm (PM_{10}), and GHG was relatively small, mainly because of the additional travel shared vehicles have to undertake in order to access travelers or to relocate. It should be noted that this simulation study assumed that shared automated vehicle users would not make more or longer trips and that the fleet (both automated and conventional vehicles) would not be electric, hybrid-electric or using alternative fuels. Finally, in another study focusing on the long-term effects of automated vehicles, Greenblatt and Saxena (2015) estimated that autonomous taxis (i.e. battery electric shared automated vehicles) in 2030 could reduce GHG emissions per vehicle per mile (a) by 87–94% compared to the emissions of internal combustion conventional vehicles in 2014 and (b) by 63–82% compared to the estimated emissions for hybrid-electric vehicles in 2030. According to these researchers, a significant increase in travel demand for autonomous taxis makes battery electric vehicle technology more cost-efficient compared to internal combustion or hybrid-electric vehicle technologies. Lower GHG intensity of electricity and smaller vehicle sizes explain the significant reductions of GHG for (battery) electric autonomous taxis. Furthermore, these researchers indicated that autonomous taxis could offer almost 100% reduction in oil consumption per mile compared to conventional vehicles because oil provides less than 1% of electricity generation in the US. Large energy savings of up to 91% per automated vehicle in 2030 were also estimated by Brown, Gonder, and Repac (2014) in a scenario that accounted for maximum impact of factors that could lead to energy savings (e.g. efficient travel, lighter vehicles, and electrification) and increased energy use (e.g. longer travel distances and increased travel by underserved populations such as youth, disabled, and elderly). However, it remains uncertain which of these factors and to what extent will they be realized in the future. Therefore, the balance between energy savings and increased energy use from automated vehicles could vary significantly. Similar uncertainty about the net effect of vehicle automation on emissions and energy consumption was reported by Wadud, MacKenzie, and Leiby (2016).

Safety

Assumptions

Over 90% of crashes are attributed to human driver (National Highway Traffic Safety Administration, 2008; data for the US context). Typical reasons include, in descending order, errors of recognition (e.g. inattention), decision (e.g. driving aggressively), performance (e.g. improper directional control), and non-performance (e.g. sleep). The advent of automated vehicles could significantly reduce traffic accidents attributed to the human driver by gradually removing the control from the driver's hands. This can be achieved through advanced technologies applied to automated vehicles with respect to perception of the environment and motion planning, identification and avoidance of moving obstacles, longitudinal, lateral and intersection control, and automatic parking systems, for example. However, any unexpected behavioral changes by a driver because of vehicle automation systems, human limitation in monitoring automation or in taking control when necessary, along with possible cyberattacks, maliciously controlled vehicles and software vulnerabilities might compromise the safety levels of automated vehicles.

Literature results

A significant amount of studies have proposed a wide variety of advanced driver assistance systems that could enhance traffic safety levels. These systems include collision avoidance (see e.g. Hayashi, Isogai, Raksincharoensak, & Nagai, 2012; Li, Juang, & Lin, 2014; Shim, Adireddy, & Yuan, 2012; Naranjo, Jiménez, Anaya, Talavera, & Gómez, 2016), lane keeping (see e.g. Lee, Choi, Yi, Shin, & Ko, 2014) and lane change assistance (see e.g. Hou, Edara, & Sun, 2015; Luo, Xiang, Cao, & Li, 2016), longitudinal speed assistance (see e.g. Martinez & Canudas-de-Wit, 2007), and intersection assistance (see e.g. Liebner, Klanner, Baumann, Ruhhammer, & Stiller, 2013). Several other studies suggested that greater levels of safety could be secured by advanced longitudinal or lateral multi-objective optimization controllers (see e.g. Gong, Shen, & Du, 2016; Khondaker & Kattan, 2015; Wang, Hoogendoorn, Daamen, van Arem, & Happee, 2015), intersection controllers (see e.g. Dresner & Stone, 2008) and path planning algorithms (see e.g. Ferguson, Howard, & Likhachev, 2008; Kuwata et al., 2009) with specific safety requirements.

Although advanced driver assistance systems can reduce accident exposure and improve driver behavior (see Spyropoulou, Penttinen, Karlaftis, Vaa, & Golias, 2008), adaptive behavior (i.e. the adoption of riskier behavior because of over-reliance on the system) may have adverse effects on traffic safety (see Brookhuis et al., 2001). For example, Hoedemaeker and Brookhuis (1998) showed that the use of ACC may induce the adoption of higher speed, smaller minimum time headway and larger brake force. Rudin-Brown and Parker (2004) indicated lower performance in brake light reaction time and lane keeping for ACC users. Markvollrath, Schleicher, and Gelau (2011) reported delayed reactions (i.e. speed reduction) for ACC users when approaching curves or entering fog, while Dixit, Chand, and Nair (2016) showed that reaction times in taking control of the vehicle after disengagement of the autonomous mode increases with vehicle miles travelled. Xiong, Boyle, Moeckli, Dow, and Brown (2012) showed that drivers' adaptive behavior—and therefore the safety implications of ACC—is related to trust in automation, driving styles, understanding of system operations and the driver's personality. Furthermore, safety levels might not substantially increase (or even decrease) until high penetration rates of fully automated vehicles are realized. For example, human driving performance could degrade in level 3 of automation because people have limitations when monitoring automation and taking over control when required (see e.g. Strand, Nilsson, Karlsson, & Nilsson, 2014; Young & Stanton, 2007). Moreover, automated vehicles might negatively influence a driver's behavior when using conventional vehicles in mixed traffic situations by making them adopt unsafe time headways (contagion effect; see Gouy, Wiedemann, Stevens, Brunett, & Reed, 2014).

Cyberattacks could also be an important threat for traffic safety. According to Petit and Shladover (2015), global navigation satellite systems (GNSS) spoofing and injection of fake messages into the communication between vehicles are the two most likely and most severe attacks for vehicle automation. Amoozadeh et al. (2015) simulated message falsification and radio jamming attacks in a CACC vehicle stream, influencing the vehicles' acceleration and space gap, respectively. These researchers showed that security attacks could compromise traffic safety, causing stream instability and rear-end collisions. Also, Gerdes, Winstead, and Heaslip (2013) showed that the energy expenditure of a platooning system could increase by up to 300% through the attack of a malicious vehicle, influencing the motion (braking and acceleration) of surrounding vehicles.

Social equity

Assumptions

The social impacts and distribution effects of a transport system can be significant. Vulnerable social groups, such as the poorest people, children, younger, older, and disabled people can suffer more from these impacts, resulting in their limited participation in society and potentially, in social exclusion (Lucas & Jones, 2012). The introduction of automated vehicles could have both positive and negative implications for social equity. Automated vehicles could offer the social groups that are currently unable to own or drive a car (e.g. younger, older and disabled people) the opportunity to overcome their current accessibility limitations. For example, not only people with physical and sensory (vision, hearing) disabilities, but also younger and older people, could use automated (shared) on demand services to reach their destinations. However, the first automated vehicles in the market are likely to be quite expensive, thus limiting these benefits to only the wealthier members of these groups for certain time. Safety benefits might also be unevenly distributed among different social groups. Owners of automated vehicles will probably enjoy higher levels of travel safety compared to drivers of conventional vehicles. Moreover, potential spread of urban activities and possible reduction of public transport services (especially buses) might further limit access to activities for poorer social groups. On the other hand, potential conversion of redundant road space to bicycle and pedestrian infrastructures (especially infrastructures that connect with high capacity public transport) could offer accessibility benefits to vulnerable population groups. Finally, the increase of vehicle-sharing services and the subsequent possible decrease of the requirements for construction of off-street parking spaces could increase housing affordability.

Literature results

Eby et al. (2016) reported, in their review paper, a positive effect (i.e. avoiding crashes, enhancing easiness and comfort of driving, increasing place, and temporal accessibility) of many in-vehicle technologies (e.g. lane departure warning, forward collision warning/mitigation, blind spot warning, parking assist systems, navigation assistance, and ACC) for older drivers. Such improvements could allow older adults to drive for more years despite declining of their functional abilities. Harper et al. (2016) estimated the extent to which total travel demand could increase in the US because of an increase in travel demand by the non-driving, elderly, and people with travel-restrictive medical conditions. They assumed that in a fully automated vehicle context, people currently facing mobility restrictions would travel just as much as normal drivers within each age group and gender. They found that the combined increase in travel demand from different social groups could result in a 14% increase in annual light-duty VMT for the US population. Finally, Mladenovic and McPherson (2016) analyzed the opportunities arising from vehicle automation to incorporate social justice in future traffic control systems in terms of efficiency and equal access.

Economy

Assumptions

Automated vehicles could bring significant economic benefits to individuals, society and businesses, but they may also induce restructuring and possible losses in some industries as well. The effects on GTC are distinguished from other effects that are relevant for the economy. Looking at the GTC effects, improved traffic safety could prevent accidents, thus avoiding the costs to society of accidents, such as human capital losses, medical expenses, lost productivity and quality of life, property damage, insurance, and crash prevention costs. A reduction in congestion delays would mean less travel costs for individuals and reduced direct production costs for businesses. Moreover, less congestion delays, along with increased potential for performing other activities (e.g. working or meeting) while on the move, could result in productivity gains. Finally, an increase in shared automated vehicle services would save individuals significant (fixed) costs associated with car ownership without compromising their mobility needs.

Other effects are now discussed. The reduction of off-street parking requirements (ground floor level parking, parking lots or multi-story parking garages) could allow the development of more economically productive activities (e.g. residential, commercial or recreational). However, a possible massive reduction in car ownership levels might have a critical negative impact on the automotive industry. New business models in this industry are likely to emerge, reflecting the convergence of different technologies in automated vehicles, while car-related industries might experience losses (e.g. motor vehicle parts, primary and fabricated metal, and plastics and rubber products). Also, jobs in professional and technical services, administration, wholesale and retail trade, warehousing, finance and insurance, and management of automotive companies could be negatively affected by the reduction of turnover in the automotive industry. Full vehicle automation could also directly lead to job losses for various professions such as taxi, delivery, and truck drivers. On the other hand, new jobs in hardware and software technology for automated vehicles might be generated. It is likely that such job related changes will vary between countries and regions. Finally, overall household expenditures can change because of automated vehicles (either increase or decrease). This could subsequently influence expenditures on other goods or services (assuming constant saving rates). Such changes in households' expenditures could create or reduce jobs in various sectors.

Literature results

A first systematic attempt to provide an order-of-magnitude estimate about both the social and private economic impacts of automated vehicles in the US context was made by Fagnant and Kockelman (2015). Their estimation took into account the safety, congestion, parking, travel demand and vehicle ownership impacts and was based on several assumptions about market share, the number of automated vehicles, fuel saving, delay reduction, crash reduction, and VMT, among other things. Their results showed that social benefits per automated vehicle per year could reach $2960 (10% market share) and increase up to $3900 (90% market share) if the comprehensive costs of crashes, in the context of pain, suffering and the full value of a statistical life, are taken into account. These estimations were based on the assumption that crash and injury rates would be reduced by 50% and 90% for 10% and 90% market penetration rate of automated vehicles, respectively. The main reason behind such significant reductions in crash rates is assumed to be the near-elimination of crashes caused by human error because of the vehicle automation technology. These researchers also showed that benefits for individuals are likely to be small, assuming current technology costs at $100,000. Yet, an investment in this technology when purchase price drops to $10,000 seems to generate a positive return rate for many individuals, even with quite low values of time. Another study examined the susceptibility of 702 occupations to technological developments (Frey & Osborne, 2017). This study concluded that about 47% of total US employment across all sectors of the economy, including occupations in the transportation and logistics sector (e.g. taxi, ambulance, transit, delivery services, heavy truck drivers, chauffeurs, parking lot attendants, and traffic technicians) has a very high risk (probability of 0.7 or higher) of being replaced by computer automation within next two decades. This study assumed that not only routine, but also non-routine cognitive and manual tasks would be increasingly susceptible to automation because of the expansion of computation capabilities (i.e. machine learning and mobile robotics) and the decrease of the market price of computing in the future. Yet, it was also assumed that non-routine tasks involving perception and manipulation, creative, and social intelligence would still be extremely difficult to automate in the near future.

Public health

Assumptions

Public health benefits might result from reduced congestion, lower traffic noise, increased traffic safety, and lower emissions from automated vehicles. Literature has shown a clear positive association between morbidity outcomes, premature mortality rates, stress, and traffic congestion (see Hennessy & Wiesenthal, 1997; Levy, Buonocore, & von Stackelberg, 2010; Miedema, 2007). Furthermore, the enhancement of road capacity, along with the reduction of on-street parking demand, might allow conversion of redundant road space into bicycle and pedestrian infrastructures. Several studies have indicated that the provision of such infrastructures is associated with higher levels of use of active modes (Dill & Carr, 2003; Buehler & Pucher, 2012) and subsequently with important public health benefits (e.g. obesity and diabetes; see Pucher, Buehler, Bassett, & Dannenberg, 2010; Oja et al., 2011). However, an increase in vehicle use because of automated vehicles (either more or longer vehicle trips) could also have a negative impact on public health, since levels of physical activity is likely to decrease.

Literature results

No systematic studies were found about the implications of automated vehicles for public health.

Conclusions and directions for future research

So far, current literature has mainly explored the technological aspects of vehicle automation and its impacts on driver and traffic flow characteristics. However, interest in the wider implications of automated vehicles is constantly growing as this technology evolves. In this paper, the effects of automated driving that are relevant to policy and society were explored, literature results about these effects were reviewed and areas for future research were identified. This review is structured, based on the ripple effect concept, which represents the implications of automated vehicles at three stages: first-order (traffic, travel cost, and travel choices), second-order (vehicle ownership and sharing, location choices and land use, and transport infrastructure), and third-order (energy consumption, air pollution, safety, social equity, economy, and public health). General conclusions are presented below and more specific ones for first, second and third order impacts, along with suggestions for the future research are presented in subsequent sections.

Literature about the policy and society related implications of automated driving is rapidly evolving. Most studies in this review are dated after 2010. This does not mean that research on development of automated vehicle systems and their implications has only been done in the last 7 years. Bender (1991) offers a comprehensive overview of the historic development of automated highway systems from the late 1950's up to about 1990 (e.g. the General Motors' systems). Moreover, several explorative or in-depth modeling studies examined a wide arrange of the impacts of automated highway systems several decades earlier (see e.g. congestion, travel speed, vehicle hours of delay, Benjamin, 1973; Miller, Bresnock, Shladover, & Lechner, 1997; emission rates, Barth, 1997) or initiated discussions about the implications of these systems for safety and driver convenience (Ward, 1994), infrastructure and urban form, (see Miller, 1997) and social equity (see Stevens, 1997). These studies can offer valuable information about the historical evolution of automated systems and the initial estimations of their impacts.

The majority of the studies in our literature review have explored impacts on capacity, fuel efficiency, and emissions. Research on wider impacts and travel demand in particular has started to pick up during the last 3 years. The implications of automated vehicles for the economy, public health, and social equity are still heavily under-researched (see Table 2).

The policy and societal implications of automated vehicles involve multiple complex dynamic interactions. The magnitude of these implications is expected to increase with the level of vehicle automation (especially for level 3 or higher), the level of cooperation (vehicle-to-vehicle and vehicle-to-infrastructure), and the penetration rate of vehicle automation systems. The synergistic effects between vehicle automation, sharing, and electrification can strengthen the potential impacts of vehicle automation. Yet, the balance between the short-term benefits and the long-term impacts of vehicle automation remains an open question.

Further research in a number of areas, as indicated in following sections, could reduce this uncertainty. A holistic evaluation of the costs and benefits of automated vehicles could help with urban and transport policies, ensuring a smooth and sustainable integration of this new transport technology into our transportation systems.

First-order implications of automated driving

Conclusions

First-order implications of automated vehicles comprised travel cost, road capacity, and travel choices. The fixed cost of automated vehicles is likely to reduce over time. GTC will possibly be lower while both road capacity and travel demand will probably increase in the short term.

Vehicle automation can result in travel time savings. Simulations have explored this assumption on highways, intersections and contexts involving shared automated vehicles. Intersections appear to have more room for travel time optimization compared to highways, while a higher penetration rate of vehicle automation systems seems to result in more travel time savings. Literature results also suggest that vehicle automation systems could result in lower fuel consumption and subsequently reduced travel cost in the short term. Research on various aspects of the third component of GTC (travel effort) is rather limited. Moreover, there is still very little to read in existing literature about the impact of vehicle automation on the values of time, leaving a striking gap in the literature on this subject. Most, studies have focused on incorporating comfort (in terms of acceleration and jerk) as the optimizing metric in path-planning algorithms. Yet, human comfort is influenced by many other factors (e.g. time headway), some of which remain unexplored (e.g. motion sickness, apparent safety, and natural paths). Therefore, there is no conclusion about the balance of all comfort related effects. Also, studies about vehicle automation impacts on travel time reliability and on utilization of travel time while on the move are scarce.

Research results show that automated vehicles could have a clear positive impact on road capacity in the short term. The magnitude of this impact is related to the level of automation, cooperation between vehicles and the respective penetration rates. A 40% penetration rate of CACC appears to be a critical threshold for realizing significant benefits on capacity (>10%), while a 100% penetration rate of CACC could theoretically double capacity. Capacity impacts at level 3 or higher levels of vehicle automation and more advanced levels of cooperation among vehicles but also between vehicles and infrastructure (e.g. multi-platooning leaders, intersection control systems, and variable speed limits) could well exceed this theoretical threshold.

Most studies show that automated vehicles could induce an increase of travel demand between 3% and 27%, due to changes in destination choice (i.e. longer trips), mode choice (i.e. modal shift from public transport and walking to car), and mobility (i.e. more trips). Additional increases in VMT are possible for shared automated vehicles because of empty vehicles traveling to the next customer or repositioning. However, one study (Childress et al., 2015) indicated that if user costs per mile are very high in a shared automated vehicle based transportation system, VMT may actually be reduced. The same study attained mixed, non-conclusive results about the trade-off between increased travel demand, capacity increases and congestion delays. No study took into account the potential changes in land use patterns, which may also influence future travel demand.

Directions for future research

There is still a critical knowledge gap about the impact of vehicle automation on individual components of travel effort (i.e. comfort, travel time reliability and utilization of travel time while on the move). For example, how can factors such as motion sickness and perceived safety affect the travel comfort of automated vehicles? To what extent can vehicle automation systems reduce travel time variability? How will people utilize available time in automated vehicles? Also, what is the collective impact of the different components of travel effort on values of time for different socioeconomic groups and trip purposes? Evidence about these individual factors—and subsequently GTC—can offer valuable input to a multitude of other related areas of research, such as the impacts on travel choices, accessibility and land uses, energy consumption, and air pollution.

Additional research on travel demand impacts is critical as well. Possible travel demand changes will to a large extent determine the magnitude of several of the other impacts of automated vehicles. Future studies should further explore travel demand implications not only because of changes in destination choice, mode choice and relocation of (shared) automated vehicles but also because of possible changes in land uses, parking demand and latent demand from social groups with travel-restrictive conditions.

Furthermore, although first-order impacts of vehicle automation on capacity are well-researched, potential trade-offs between additional capacity and GTC associated factors such as travel comfort, safety, and travel time reliability remain relatively unexplored.

Second-order implications of automated driving

Conclusions

Second-order implications of automated vehicles comprised vehicle ownership and sharing, location choices, land use and transport infrastructure. Literature results suggest that shared automated vehicles could replace a significant number of conventional vehicles (from about 67% up to over 90%) delivering equal mobility levels. The overall reduction of the conventional vehicle fleet could vary according to the automated mode (vehicle-sharing, ridesharing, shared electric vehicle), the penetration rate of shared automated vehicles and the presence or absence of public transport. For example, a wide penetration of shared automated vehicles supported by a high capacity public transport system would be expected to result in the highest reduction of conventional vehicle fleet. Few studies have explored the impact of automated vehicles on location choices and land use. According to their results automated vehicles could enhance accessibility citywide, especially in remote rural areas, triggering further urban expansion. Automated vehicles could also have a positive impact on the density of economic activity at the center of the cities. Parking demand for automated vehicles could be shifted to peripheral zones, but could also remain high in city centers, if empty cruising of shared automated vehicles is not allowed. Moreover, several studies showed that shared automated vehicles can significantly reduce parking space requirements up to over 90%. Finally, less wheel wander and increased capacity because of automated vehicles could accelerate pavement-rutting damage. Yet, increase in speed of automated vehicles could compensate for such negative effect by decreasing rut depth.

Directions for future research

A critical research priority is the exploration of the implications that automated vehicles have for accessibility and, subsequently, for land uses. Results from this kind of research will give some input into the assessment of many other longer-term impacts of automated vehicles, including energy consumption, air pollution, and social equity. A comprehensive assessment of accessibility changes should focus on all components of accessibility (transportation, land use, individual, and temporal).

The impacts of automation on vehicle ownership could be further explored. Thus far, research has discovered how many shared automated vehicles can substitute conventional vehicles to serve (part of) current mobility demand. Yet, a more important question is: what will the size of vehicle fleet reduction be if possible changes in travel demand and the willingness of people to own or use shared automated vehicles are taken into account?

Possible changes in urban streetscape and building landscape because of vehicle automation also offer an area for design research and experimentation. To what extent will vehicle automation affect the level and geographical distribution of parking demand? What will be the potential changes in the geometrical characteristics of roads and intersections because of capacity enhancement, motion stability of automated vehicles and automated intersection management? How will potential new urban space be redistributed among different land uses (e.g. between open space and new buildings) and users (e.g. vehicles, cyclists, and pedestrians)?

Third-order implications of automated driving

Conclusions

Third-order implications of automated vehicles comprised energy consumption and air pollution, safety, social equity, the economy, and public health. First-order impacts on fuel efficiency, emissions and accident risk were also included in this section of our analysis for consistency reasons. Literature results suggest that the use of automated vehicles can result in fuel savings and lower emissions in the short term. The net effect of vehicle automation on energy consumption and GHG emissions in the long term remains uncertain. Traffic safety can improve in the short term but behavioral adaptation and low penetration rates of vehicle automation might compromise these benefits. Few studies on the economic and social equity impacts exist, while no systematic studies were found for public health implications of automated vehicles.

Various longitudinal, lateral and intersection control algorithms and optimization systems can offer significant fuel savings and lower emissions of NOx, CO, and CO_2. Studies reviewed in this paper reported fuel savings up to 31% for longitudinal and lateral movement controllers and up to 45% for intersection controllers. Both fuel economy and emission reductions are reported higher as the penetration rate of vehicle automation systems increases. Furthermore, shared use of automated vehicles is associated with reduced emissions (VOC and CO in particular) because of the lower number of times a vehicles starts. One study (Greenblatt & Saxena, 2015) associated the long-term impacts of battery electric shared automated vehicles with up to 94% less GHG and nearly 100% less oil consumption per mile, compared to conventional internal combustion vehicles. Yet, several factors could lead to increased energy use (e.g. longer travel distances and increased travel by underserved populations such as youth, disabled, and elderly). Thus, the net effect of vehicle automation on energy consumption and GHG emissions remains uncertain.

As for traffic safety, literature results suggest that advanced driver assistance systems can reduce exposure to accidents. Level 3 or higher levels of automation can further enhance traffic safety. However, as long as the human driver remains in-the-loop, behavioral adaptation—namely the adoption of riskier behavior because of over-reliance on the system—can compromise safety benefits. Moreover, fully automated vehicles might not deliver high safety benefits until high penetration rates of these vehicles are realized. Cyberattacks, such as message falsification and radio jamming, can compromise traffic safety as well.

Finally, research on the impacts of vehicle automation on the economy, social equity and public health is almost non-existent. Automated vehicles could have significant impacts on all three areas. Results from one study (Fagnant & Kockelman, 2015) indicate that social benefits per automated vehicle per year could reach $3900 where there is a 90% market share of automated vehicles, while a positive return rate for individuals should not be expected before the additional cost for vehicle automation drops to $10,000. Another study (Frey & Osborne, 2017) concluded that occupations in the transportation and logistics sectors (e.g. taxi, ambulance, transit, delivery services, heavy truck drivers, chauffeurs, parking lot attendants, and traffic technicians) have a high probability (>0.7) of being replaced by computer automation within the next two decades. In-vehicle technologies can have positive effects (i.e. avoiding crashes, enhancing easiness and comfort of driving, increasing place, and temporal accessibility) for elderly. Such improvements could extend driving life expectancy for older adults. One study estimated that automated vehicles could induce up to 14% additional travel demand from the non-driving, elderly, and people with travel-restrictive medical conditions.

Directions for future research

The emission and fuel efficiency effects of vehicle automation are well researched. However, the magnitude of the effect at different levels of automation and penetration rates could be further tested. A clear research priority is the exploration of the long-term effects of automated vehicles on energy consumption and emissions, taking into account potential travel demand changes but also the additional synergistic effects between vehicle automation, sharing, and electrification and possible changes in vehicle size. Results from this kind of research will allow us to better assess the balance between the short-term benefits and the long-term impacts of automated vehicles on energy consumption and emissions.

Another critical research priority concerns safety implications in the transitional contexts of fully automated and conventional vehicles. To what extent will vehicle automation and human drivers of conventional vehicles compromise the performance of each other in mixed traffic situations? A better understanding of the types of cyberattacks and their potential impacts on traffic safety is critical too.

A comprehensive assessment of economic, public health and social impacts is also missing from current literature. For example, what could be the scale of job losses (or gains) due to full vehicle automation? Which sectors and which countries and/or regions would be most affected? And what could be the strategies to mitigate the economic impacts of expected job losses? The impact of vehicle automation on public health is also an important area for further research. To what extent will vehicle automation induce lower levels of physical activity and what will the possible impacts be on activity-related public health issues, such as obesity and diabetes? The exploration of social impacts and distribution effects through the analysis of potential accessibility changes would also contribute to a better understanding of the social implications of automated vehicles. To what extent could (shared) automated vehicles influence the ability of vulnerable social groups (e.g. people with physical, sensory and mental disabilities, younger or older people, and single parents) to access economic and social opportunities? How benefits stemming from vehicle automation will be distributed among different social groups?

Methodological challenges in exploring the implications of automated vehicles

To further explore the implications of automated vehicles, we will have to face several methodological challenges.

One critical issue is that this technology (especially at level 3 or higher levels of automation) is still in its infancy. Thus, no adequate empirical data about the use of automated vehicles exist yet. Therefore, studies have mainly made use of micro and macro traffic simulation, driving simulators, field experiments and analytical methods to explore first-order implications of automated vehicles on travel time, capacity, fuel efficiency, emissions, and safety. More empirical studies about first-order implications of vehicle automation are a clear priority as this technology evolves. For second and third-order implications, the armory of methods needs to expand to capture the behavioral aspects, underlying potential changes due to vehicle automation. Thus, for example, qualitative methods, such as focus groups or in-depth interviews, in combination with quantitative methods, like stated choice experiments, could be used for exploring questions about the impacts of vehicle automation on travel comfort, utilization of travel time while on the move, value of time, travel, and location choices. Yet, people may have difficulties in envisioning automated vehicles, so stated choice experiments could suffer from hypothetical bias (see Fifer, Rose, & Greaves, 2014). More creative techniques such as virtual reality or serious gaming would be useful in behavioral experiments about the impacts of automated vehicles. Another approach may be to investigate similar systems that are essentially automated. For example, investigate the value of time for train commuters who both live and work near stations, as for them a train trip is essentially automated. Travel behavior changes because of ICT (e.g. telecommuting) could offer insights into possible behavioral changes because of vehicle automation. Expert opinion research (e.g. Delphi technique) could also be an alternative method.

Agent-based and activity-based models could then be used to simulate possible changes in travel demand, vehicle ownership and other environmental indicators, such as energy consumption and emissions. The connection of travel models with land use models (in so-called Land Use—Transport Interaction, or LUTI models) would also allow potential long-term land use impacts on travel demand to be captured. Alternative approaches could involve empirical models for the analysis of comparable systems and their potential impacts on land use (e.g. valet parking, car-free neighborhoods, and high speed train). Finally, accessibility metrics and measures of inequality could be used in the analysis of the social equity impacts of automated vehicles.

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https://www.dmv.org/articles/self-driving-vehicles-privacy-concerns

This article provides an example of potential public backlash based on privacy concerns. DMV.org is a nonprofit organization, not a government agency.

Autonomous Cars, Big Data, and the Post-Privacy World

By: Bridget Clerkin October 2, 2017

Carmakers are tracking more data than ever as cars get smarter—including information on your health and communications. New government guidelines place little to no restrictions on what they can do with that data.

First they came for the regulations…

The change happened last month, in an announcement of little fanfare: Department of Transportation Secretary Elaine Chao issued a new set of proposals for the official roll-out of self-driving cars.

Her agency had done away with the 15-point plan released last year by the Obama administration and replaced it with a "clearer, more streamlined, less burdensome" document consisting of a loose set of guidelines for the automotive industry.

Among other intentions, the voluntary policies hope to herald a technology in autonomous driving that can curb dangerous human driving habits—responsible for "9 out of 10 serious roadway crashes," the document declares—and institute at least a vague outline of what the federal government wants to see in the rides of the future.

But it's what the authors of the DOT report are turning a blind eye to that's the problem.

The 26-page list of suggestions makes virtually no mention of consumer privacy, meaning self-driving cars could not only record where a driver is going, who they're with, and what they're saying—but also share that information directly with corporations or sell it to the highest bidder.

The vehicles represent Big Data's Holy Grail, and the new regulations do nothing to stop them from spying on drivers.

A Game of iSpy

Just how much will cars know about their drivers?

For starters, information immediately available to them: the direction drivers are traveling in; how fast they're getting there; what stops they're making.

But extrapolated out across a lifetime, the vehicles will be privy to the much more intimate life patterns: not just current location, but all of the places a driver has been. Not just the destination they're headed toward, but all the places they frequent—or the spots they've stopped visiting, or started flat-out avoiding.

Many new vehicle models already connect some of these dots, using previously captured data to infer a driver's preferences, and suggest certain songs or routes to them, among other conveniences. But cars are becoming increasingly smarter, and their measurements have become increasingly intimate—some even going as far as reading a driver's biometrics.

Anything from the line of a driver's gaze to the beat of their heart is or has been recorded by a vehicle, arguably to ensure greater safety by making sure, among other things, that eyes are on the road and motorists are in good health while driving.

At their most extreme, cars will even be able to know *who* is behind the wheel, using physical hints like fingerprints or faces to determine who's driving—and adjust all personal settings accordingly.

This doesn't include information gleaned from the myriad new sensors, cameras, and microphones being built into the cars, which will be able to record not just the contents of the vehicle but what's going on outside it. The autos will also have access to any communique that transpires while a phone is synced up to a car's Bluetooth system. (The National Automobile Dealers Association has received so many questions about these latter features that they've issued a brochure to advise interested buyers on everything that may be monitored.)

And it's not just the breadth of what cars know that's expanding; it's also the ways that information can be utilized—or exploited.

An Optimal Situation

Personal data is extremely valuable to corporations, and connected vehicles may provide them with tons of new data to mine.

App companies and other Big Data farmers have a word for this massive information intake: "optimizing." They encourage consumers to connect, sign on, and share because learning more, they say, will let them set the stage for a more personal—and therefore better—experience. Many connected car companies have used the same line.

But just how much is "optimized" time worth to them?

Concrete numbers are hard to come by, but it's been reported that Google and Facebook alone sell personal "profiles"—a potent mix of demographical data and cultivated preference or search histories—for up to $20 per user.

In 2012, the online data broker industry raked in a total of $426 million in revenue from selling personal information, according to the latest report on the subject compiled by the Federal Trade Commission (FTC). Its most profitable sector by far was marketing, with brokers making more than $196 million that year by selling a mix of data-based products—from snippets of "identifying information," such as names, social media usage, race, religious affiliation, parental status, credit card usage, and net worth, among others, used to help clients understand who's visiting their websites, to "marketing lists," where data sets of like-minded individuals are sold as a bundle to firms who are more interested in targeted advertising.

And that's just the tangible value of user data. The wealth of knowledge it offers whomever possesses it is incalculable—and nearly infinitely applicable. (That's partially because of how integrated machines have become, allowing users to generate a daily information trail without realizing it. After requesting to see the intel dating app Tinder had kept on her, one reporter alone was sent more than 800 pages of data.)

As users' main means of transport, cars will have greater access into their personal lives than even dating apps. Such information can be used for anything from cultivating more accurate auto insurance estimates to much more elaborate acts of advertising—conceivably even using precise geo-tracking technology to let a driver know when they're approaching a favorite store and what they have on sale.

The data collection itself could also prove an enticing invitation for those with more nefarious motivations.

But to see how the Department of Transportation plans to deal with the issue, you'll practically have to read between the lines.

A Historical Footnote

When the first list of self-driving car suggestions was released in September 2016, privacy was one of the 15 checkpoints its authors asked auto manufacturers to consider when building their autonomous vehicles. Specifically, the previous policies said car owners should know which metrics were being tracked and have the chance to opt out of any information collection they weren't comfortable with.

True to its "streamlined" promise, however, the new document (officially released by the National Highway Traffic Safety Administration [NHTSA]—a branch of the DOT) whittles down any appearance of the word "privacy" to exactly four uses—including two in the footnotes.

It's in this list of annotated afterthoughts where the NHTSA's new consumer privacy policy regarding self-driving cars can be found: the issue, its authors say, *is none of its business*—although they do briefly mention that "Privacy and Ethical Considerations are also important."

On a separate website to which the footnote links, agency officials say consumer privacy is "not directly relevant to motor vehicle safety" and should instead be overseen by the FTC. (For their part, FTC officials called for more leadership from the NHTSA—and more testing exemptions on the vehicles—in their latest report on the subject, but failed to list a single privacy recommendation.)

Still, NHTSA officials acknowledge the "significant amount of vehicle data generated" by using the cars may be considered "sensitive and personal" to some drivers. They ask automakers to consider this fact when fostering consumer "*acceptance*" of the technology—but don't comment on their general use of it, and stop short of any attempt to regulate the data collection.

The same *laissez-faire* attitude is not extended to metrics on the automakers themselves, though. The corporations are officially advised by the NHTSA to keep some of their own data private—including anything that could be considered “confidential business information.” (The terminology mirrors that from recent legislation passed by the House of Representatives, which uses the phrase—shortened to “CBI”—to describe, among other things, any data related to crashes the cars are involved in.)

The new guidelines direct manufacturers to submit Voluntary Safety Self-Assessments—but warns them to keep any CBI out of them *“as it would be information available to the public.”*

So how should users deal with technology they’ll know so little about, but which will know so much about them?

A Checkered Solution

Without strong backing by the federal government, drivers may have to rely piecemeal on carmakers to protect their privacy.

Indeed, some manufacturers have already heeded the call, creating a list of privacy principles they promise to follow starting with their 2017 models. (The collective, called the Alliance for Automobile Manufacturers, is comprised of 12 major carmakers, including BMW, Fiat Chrysler, Ford Motor Company, General Motors, Jaguar Land Rover, Mazda, Mercedes-Benz USA, Mitsubishi Motors, Porsche, Toyota, Volkswagen, and Volvo.)

Among their promises, the group says it will keep some data private, but it also acknowledges that other information may be used for marketing—or otherwise sent to third parties. But officials for the companies say a car owner’s consent will be sought before their information is sold. (Concerned consumers, the alliance suggests, can always ask what information on them will be collected—and why.)

Still, the rules aren’t enforced by any outside entity, and automakers who break their promises will likely never see punishment.

In the meantime, it seems drivers will just have to accept that the powers that be will know much more than their Internet histories—they’ll know the exact direction they’re headed

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Unmanned aircraft systems: Surveillance, ethics and privacy in civil applications

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A B S T R A C T

This paper examines how the use of unmanned aircraft systems (UASs) for surveillance in civil applications impacts upon privacy and other civil liberties. It argues that, despite the heterogeneity of these systems, the same "usual suspects" – the poor, people of colour and anti-government protesters – are targeted by UAS deployments. It discusses how current privacy-related legislation in the US, UK and European Union might apply to UASs. We find that current regulatory mechanisms do not adequately address privacy and civil liberties concerns because UASs are complex, multimodal surveillance systems that integrate a range of technologies and capabilities. The paper argues for a combination of top-down, legislated requirements and bottom-up impact assessments to adequately address privacy and civil liberties.

1. Introduction

Unmanned aerial vehicles (UAVs) can generally be defined as a "device used or intended to be used for flight in the air that has no on-board pilot".[1] These devices are sometimes referred to as "drones", which are programmed for autonomous flight, and remotely piloted vehicles (RPVs), which are flown remotely by a ground control operator.[2] Current generations of UAVs "can be as small as an insect or as large as a charter flight".[3] They are often launched from a road or a small vehicle, and large enough to accommodate cameras, sensors or other information gathering equipment.[4] Recently, discussions of UAVs have used the term unmanned aircraft systems (UASs) to reflect "the fact that in addition to the unmanned aircraft, a complete UAS includes multiple pieces of ancillary equipment, such as vehicle control equipment, communications systems, and potentially even launch and recovery platforms".[5] According to McBride, the versatility of these "systems" is one of the strongest drivers in the rapid development of these technologies, where "the identification of new potential uses leads to the adaptation of the systems".[6] One such use is the deployment of UASs with cameras or sensors in law enforcement applications, which has led the Surveillance Studies Network, in its testimony to the UK

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[1] Quoted from Aviation Safety Unmanned Aircraft Programme Office, 2008, in McBride Paul. Beyond Orwell: the application of unmanned aircraft systems in domestic surveillance operations. Journal of Air Law and Commerce Summer 2009;74(3):627–62, 628.

[2] Bolkcom Christopher. Homeland security: unmanned aerial vehicles and border surveillance. Congressional research service report for Congress; 28 June 2004.

[3] Eick Volker. The droning of the drones: the increasingly advanced technology of surveillance and control. Statewatch analysis, no. 106; 2009. p. 1. http://www.statewatch.org/analyses/no-106-the-droning-of-drones.pdf.

[4] McCormack Edward D. The use of small unmanned aircraft by the Washington State Department of Transportation. Washington State Transportation Center; June 2008.

[5] McBride, op. cit., 2009. p. 629. See also Directorate of Airspace Policy. CAP 722: Unmanned aircraft system operations in UK airspace – guidance. Civil Aviation Authority; 6 Apr 2010.

[6] McBride, op. cit., 2009. p. 629.

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House of Lords, to assert that UAVs represent one of the technological forms that characterise "new surveillance".[7]

Despite recent growth in the UAV/UAS market, UAVs have a relatively long history. The first unmanned aircraft was a torpedo developed in 1915 for the US Navy, which was designed to fly to a specific location and drive into its target.[8] In the Second World War, they were used as radio-controlled targets and for reconnaissance missions.[9] In the 1990s, the Defense Advanced Research Projects Agency (DARPA) and NASA began research into further uses of UAVs, and a number of well-known UAVs such as the Helios, Proteus, Altus Pathfinder and Predator (which was first used by the US in the Gulf War) resulted from this effort.[10] Drones were so effective in the Gulf War that "Iraqi troops began to associate the sound of the little aircraft's two-cycle engine with an imminent devastating bombardment", which led to "the first instance of human soldiers surrendering to a robot".[11] Growth in this area has recently increased exponentially, particularly because of developments in lightweight construction materials, microelectronics, signal processing equipment and GPS navigation.[12] More than 50 nations currently use drones for military reconnaissance, intelligence-gathering and targeting[13] and as of 2003 at least three dozen nations had active UAV development or application programmes.[14] However, the civil market for UASs is the largest area of predicted sector growth in the next few years. For example, the UK Civil Aviation Authority has stated that model aircraft have been flying successfully for years "performing aerial work tasks, effectively operating as UAVs".[15] Furthermore, a worldwide survey of existing UASs in 2004 found that 79 per cent are aimed at civil research or dual-purpose operations and that this is likely to continue.[16] This emerging civil market includes potential applications such as public security, law enforcement, border patrol, emergency services and commercial services.[17]

This paper examines how the use of UASs for surveillance in civil applications impacts upon privacy and other civil liberties. It argues that, despite the heterogeneity of these systems, the same "usual suspects" are targeted by deployments of UASs. It discusses how current legislation mechanisms might apply to UASs, with specific attention to privacy-related legislation in the USA, European Union and UK. It finds that current regulatory mechanisms do not adequately address privacy and civil liberties concerns because UASs are complex, multimodal surveillance systems that integrate a range of technologies and capabilities. Furthermore, the inadequacy of current legislation mechanisms results in disproportionate impacts on civil liberties for already marginalised populations.

2. Surveillance and civil liberties

Much critique surrounding the introduction of surveillance technologies such as UASs, or their expansion from military to civil applications, has centred on civil liberties concerns. Privacy represents a key framework through which surveillance technologies, and particularly "new surveillance"[18] technologies, are critiqued,[19] although scholars have had difficulty in agreeing on a precise conceptualisation. Whitman described privacy, important though it may be, as "an unusually slippery concept",[20] while Solove, more recently, has said that privacy "is a concept in disarray. Nobody can articulate what it means."[21] Although a widely accepted definition of privacy remains elusive, there has been rather more consensus on a recognition that privacy comprises multiple dimensions, which privacy guru Roger Clarke specified as privacy of the person, privacy of personal data, privacy of personal behaviour and privacy of personal communication.[22] Similarly, Solove asserts that privacy is best understood as a "family of different yet related things".[23] One aspect of this family is data protection, where some law-makers have attempted to use data protection legislation to mitigate concerns around the effects of surveillance. However, Lyon argues that data protection is difficult to connect to a basic

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[7] House of Lords Select Committee on the Constitution. Surveillance: citizens and the state, vol. 2. HL paper 18, second report, session 2008–09. London: House of Lords; 6 Feb 09.

[8] Dunlap Travis. Comment: we've got our eyes on you: when surveillance by unmanned aircraft systems constitutes a Fourth amendment search. South Texas Law Review Fall 2009;51(1): 173–204.

[9] The Economist. Unmanned aircraft: the fly's a spy. 1 Nov 2007. http://www.economist.com/displaystory.cfm?story_id=10059596.

[10] Nonami Kenzo. Prospect and recent research and development for civil use autonomous unmanned aircraft as UAV and MAV. Journal of Systems Design and Dynamics 2007;1(2):120–8.

[11] Wilson JR. UAVs: a worldwide roundup. Aerospace America June 2003. https://www.aiaa.org/aerospace/Article.cfm?issuetocid=365&ArchiveIssueID=39.

[12] The Economist, op. cit., 2007.

[13] Strategic Comments. The drones of war. 2009;15(4):1–2.

[14] Wilson, op. cit., 2003.

[15] Haddon DR, Whittaker CJ. UK-CAA policy for light UAV systems. UK Civil Aviation Authority; 28 May 2004. p. 2.

[16] Ibid.

[17] FH Joanneum University of Applied Sciences. Unmanned aircraft systems – towards civil applications. Graz, Austria; 10 Nov 2009. http://www.fh-joanneum.at/aw/home/Studienangebot_Uebersicht/fachbereich_information_design_technologien/lav/news_events_ordner_lav/Archiv/~btch/lav_news_091110/?lan=de.

[18] According to Gary Marx, "new surveillance" is characterised by new forms of technology, gathering information from categories of interest rather than specific persons, an increase in the amount of data collected, remote operation, less coercive data collection, a routinisation of surveillance and can involve multiple measures in combination. See Marx Gary T. What's new about the new surveillance?: classifying for change and continuity. Surveillance & Society 2002;1(1):9–29.

[19] Lyon David. Surveillance after September 11. Cambridge: Polity Press; 2003.

[20] Whitman James Q. The two western cultures of privacy: dignity versus liberty. The Yale Law Journal 2004;113:1151–221, 1153–4.

[21] Solove Daniel J. Understanding privacy. Cambridge MA and London: Harvard University Press; 2008. p. 12.

[22] Clarke Roger. What's 'privacy'? Australian Law Reform Commission workshop; 28 July 2006. http://www.rogerclarke.com/DV/Privacy.html.

[23] Solove, op. cit., 2008. p. 9.

human right, and thus is problematic as an over-arching civil liberties protection framework.[24]

Lyon argues that privacy is also inadequate to capture all of the negative effects of surveillance, since other civil liberties concerns, in addition to privacy, are implicated in new technologies of surveillance.[25] For example, the use of surveillance technologies may inhibit individuals' freedom of assembly or freedom of expression due to a "chilling effect" that discourages individual participation in social movements or public dissent activities.[26] In relation to profiling via data mining, Schreurs et al. discuss a right of non-discrimination within the framework of the European Convention on Human Rights.[27] Such potential for discrimination is particularly important; Coleman and McCahill argue that the use of surveillance technologies often reinforces existing social positions, particularly positions of marginalisation along the lines of race, class, gender, sexuality and age.[28] Surveillance technologies may impinge upon individuals' freedom of movement, in a clear example of Lyon's notion of social sorting. Such linkages between social position and movement are noted by Graham and Wood[29] and Finn and McCahill[30], where digitalised surveillance systems enable a privileged mobility for some individuals (e.g., the use of iris scanning systems to bypass immigration queues) while marginalised individuals find their mobility further restricted (for example, by false positive matches with individuals on "no fly" lists, or where individuals who refuse body scans at airports are prevented from flying[31]). This restriction on freedom of movement can disproportionately impact some groups of already marginalised travellers, such as Muslim women, for whom religious restrictions on modesty prevent participation in body scanning systems.[32] In addition to these civil liberties concerns around the negative effects on individuals, Lyon reminds us that, via the International Treaty on Human Rights, individuals also have a right to security.[33]

Yet, different surveillance technologies with different capabilities often require different regulatory mechanisms to minimise their impacts on civil liberties. For example, the European Parliament is considering issuing recommendations on body scanners that include provision of an alternative to body scanning technology, and Langheinrich has recommended that RFID applications should protect personal information through privacy enhancing technologies such as encryption.[34] The deployment and use of CCTV systems in public spaces are guided by codes of practice and legislation such as the UK Data Protection Act or the European Data Protection Directive 95/46/EC, while communication interceptions such as wiretapping often require a warrant signed by a judge or some other supervisory authority. The fact that the capabilities and applications of UAS devices vary so much depending upon the technologies they integrate makes it difficult to establish over-arching regulatory mechanisms to prevent intrusion on civil liberties.

3. Capabilities and applications

The expanding capabilities of UAS devices mean that they have already been used, or are currently being used, for various civil applications. Furthermore, as these capabilities are further augmented and differentiated, experts envision that UASs will be used for still more applications. However, the intersection of these capabilities and applications in deployments against individuals for law enforcement or other security-related activities means that already marginalised populations are disproportionately targeted.

3.1. *Current and future capabilities*

UASs have a range of capabilities making them useful not only for military applications, but also the bourgeoning field of civil applications. Specifically, UASs have a "niche" in performing the three Ds: dull, dirty and dangerous work, thereby protecting human pilots from fatigue and various environmental hazards. Brecher identifies the following general capabilities for unmanned aircraft systems:

- They can be deployed on demand.
- They have flexibility in tasking: e.g., surveillance, disasters, etc.
- They have "plug and play" capabilities for their payloads, making tailored systems possible.

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[24] Lyon David. Facing the future: seeking ethics for everyday surveillance. Ethics and Information Technology 2001;3:171–81.

[25] Lyon, op. cit., 2001. Raab and Wright make a similar point: "Data protection principles are an essential bedrock, but they do not fully address the range of questions that should be asked about surveillance, especially the 'new surveillance' brought about through new technologies and information systems." Raab Charles, Wright David. Surveillance: extending the limits of privacy impact assessment. In: Wright David, De Hert Paul, editors. Privacy impact assessment. Dordrecht: Springer; 2012.

[26] Cunningham David, Noakes John. What if she's from the FBI? The effects of covert forms of social control on social movements. In: Deflem Mathieu, editor. Surveillance and governance: crime control and beyond. Bingley, UK: Emerald Group Publishing Limited; 2008 and Lyon, op. cit., 2003.

[27] Schreurs Wim, Hildebrandt Mireille, Kindt Els, Vanfleteren Michaël. *Cogitas, ergo sum*. The role of data protection law and non-discrimination law in group profiling in the private sector. In: Hildebrandt Mireille, Gutwirth Serge, editors. Profiling the European citizen: cross-disciplinary perspectives. London: Springer; 2008.

[28] Coleman Roy, McCahill Michael. Surveillance and crime. London: Sage; 2011.

[29] Graham Stephen, Wood David. Digitizing surveillance: categorization, space, inequality. Critical Social Policy May 2003;23(2): 227–48.

[30] Finn Rachel L, McCahill Michael. 'Good' and 'bad' data subjects: media representations of the 'surveilled' in three UK newspapers. In: Leman-Langlois Stéphane, editor. Technocrime2. London: Routledge; 2012, forthcoming.

[31] Klitou Demetrius. Backscatter body scanners – a strip search by other means. Computer Law & Security Report 2008;24(4): 316–25, 317.

[32] Peterson Rohen. The emperor's new scanner: Muslim women at the intersection of the first amendment and full body scanners. Social Science Research Network 6 Mar 2010. http://ssrn.com/abstract=1684246.

[33] Lyon, op. cit., 2003.

[34] Langheinrich Marc. A survey of RFID privacy approaches. Personal and Ubiquitous Computing 2009;13(6):413–21.

- They can support high-resolution imagery or sensors.
- They can cover remote areas.[35]

Ollero et al. note that UASs are heterogeneous and can support the high manoeuvrability and hovering capabilities of helicopters as well as the global views and communications relay capabilities of airships.[36] In addition to these general capabilities, UASs have more specific capabilities in relation to the way they are piloted, their size, flying speed and endurance as well as the technologies they integrate.

Most large UAS are remotely piloted. In current combat operations in Iraq and Afghanistan, large UASs are "controlled by pilots working in shifts and sitting in front of a video screen thousands of miles away at an air force base in America"[37] "from a console with twin video screens shaped to resemble a plane's cockpit"[38]. BAE's HERTI can be programmed to take off, complete a full mission and land automatically.[39] Some smaller models can be carried and deployed by individuals on the ground and flown via remote control. One UAS made by AirRobot can be flown even when out of sight because it beams images from the aircraft back to video goggles worn by the operator.[40] Furthermore, not all UASs require a specially trained "pilot". Interested individuals can build a basic UAV for approximately $1000 USD using Legos, a GPS unit and model aircraft parts.[41] Individuals in Germany can reportedly rent drones for €190 per hour.[42] In terms of future developments related to flying capabilities, manufacturers are working on making UASs more autonomous as well as trying to programme swarms of vehicles that can co-operate with one another.[43] The development of "sense and avoid systems", which many researchers are exploring, will transform UAS technology and allow the devices to be deployed in a range of applications, potentially leading to their wide deployment.[44]

UASs being used in the civil sector have specific capabilities regarding their size, flying speed and endurance. General Atomics' MQ-1 Predator Bs can fly between 20 and 30 h, are 36 feet (11 m) long, have a wing span of 66 feet (26.1 m), weigh 1500 pounds (680 kg), and are powered by 900 horsepower turboprop engines.[45] These large UAVs can cost $4.5 million USD, with the accompanying ground equipment running another $3.5 million. Significantly smaller UASs have fewer capabilities. The Insitu Insight has "a 10 foot [3.05 m] wing span, a maximum altitude of 19,500 feet [5944 m], and a flight endurance of more than 20 h",[46] and Honeywell Micro Air Vehicles weigh 14 pounds (6.35 kg) and have a maximum altitude of 10,500 feet (3200 m). The SkySeer, manufactured by Octatron Inc., has a wing span of 6.5 feet (1.98 m) and weighs 4 pounds (1.8 kg). This Micro-drone which flies at 30 mph (48 kph) is significantly more cost efficient at $25,000 to $30,000 USD. The CannaChopper SUAVE 7, which weighs 7 kg and can fly up to 2 h depending on payload and fuel load, fits into the trunk of a car and can be transported easily.[47] The German AirRobot, a helicopter type UAV, measures 3 feet (.91 m) between the tips of its four carbon fibre rotor blades, and a battery-operated drone manufactured by MW Power, is 70 cm-wide and can fly up to 500 m high.[48] Both the SkySeer and the AirRobot can transmit data to a ground station, enabling an operator to see what the UAS is seeing, in real time and, if necessary, direct officers on the ground.[49] One of the main advantages of UASs is that they are almost undetectable to the person(s) or target(s) being surveilled. The OPARUS project, financed by the European Commission, states that a UAS can operate "almost in silence".[50] Similarly, BAE drones' flight ceiling of 20,000 feet (6096 m) makes them almost invisible from the ground.[51] In terms of future developments in these capabilities, the first revolves around developments in the size and shape of UAVs, or unmanned vehicles (as the case may be). These include the miniaturisation of UAVs to insect-sized surveillance vehicles that could fly through open windows,[52] which is being worked on by the Air Force Research Lab, Onera (France's national aerospace centre), Harvard University and the University of Portsmouth in the UK.[53] Another innovation is a "snake bot": an unmanned vehicle can be fitted with cameras or audio sensors and "slither undetected through grass and raise its head to look around, or even climb a tree for a better view".[54]

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[35] Brecher Aviva. Roadmap to near-term deployment of unmanned aerial vehicles (UAV) for transportation applications charge to participants. UAV 2003: roadmap for deploying UAVs in transportation specialist workshop. Santa Barbara, CA; 2 Dec 2003.

[36] Ollero Aníbal, Lacroix Simon, Merino Luis, et al. Multiple eyes in the skies: architecture and perception issues in the COMETS unmanned air vehicles project. IEEE Robotics & Automation Magazine June 2005:46–57.

[37] The Economist, op. cit., 2007.

[38] Bowcott Owen, Lewis Paul. Attack of the drones. The Guardian 16 Jan 2011. http://www.guardian.co.uk/uk/2011/jan/16/drones-unmanned-aircraft.

[39] Page Lewis. BAE in South Coast mouse-click drone spy plan: there'll be ro-birds over the white cliffs of Dover. The Register 8 Nov 2007. http://www.theregister.co.uk/2007/11/08/bae_mouse_click_robot_spy_dover_over/.

[40] Randerson James. Eye in the sky: police use drone to spy on V festival. The Guardian 21 Aug 2007. http://www.guardian.co.uk/uk/2007/aug/21/ukcrime.musicnews.

[41] The Economist, op. cit., 2007.

[42] Eick, op. cit., 2009.

[43] Bowcott and Lewis, op. cit., 2011.

[44] Eick, op. cit., 2009.

[45] Matthews William. Border patrol at 19,000 feet: UAVs take flight along Texas border – during daylight. Defense News 14 June 2010. http://www.defensenews.com/story.php?i=4668081.

[46] Dunlap, op. cit., 2009. p. 180–1.

[47] Cannachopper. Suave 7. 2009. http://www.cannachopper.com/helicopters/47-suave7.

[48] Randerson, op. cit., 2007.

[49] Bowes Peter. High hopes for drone in LA skies. BBC News 6 June 2006. http://news.bbc.co.uk/1/hi/world/americas/5051142.stm and Hull Liz. Drone makes first UK 'arrest' as police catch car thief hiding under bushes. Daily Mail 12 Feb 2010. http://www.dailymail.co.uk/news/article-1250177/Police-make-arrest-using-unmanned-drone.html#ixzz1JV7EKR1N.

[50] OPARUS. Concept and approach; 2010. http://www.oparus.eu/index.php/concept-a-approach.

[51] Lewis Paul. CCTV in the sky: police plan to use military-style spy drones. The Guardian 23 Jan 2010. http://www.guardian.co.uk/uk/2010/jan/23/cctv-sky-police-plan-drones.

[52] Nevins Joseph. Robocop: drones at home. Boston Review Jan/Feb 2011. http://www.bostonreview.net/BR36.1/nevins.php.

[53] The Economist, op. cit., 2007.

[54] Wired Magazine, quoted in Nevins, op. cit., 2011.

In terms of endurance, Nevins reports that research is being undertaken on a solar-powered UAV that could stay airborne for up to five years.

These drones can also incorporate attachments, which themselves have specific capabilities. For example, the Insitu Insight carries out surveillance through a camera attached to the underside of the vehicle, and can incorporate low-light and infrared cameras enabling officers to find heat signatures; however, carrying both cameras decreases the vehicle's endurance to 15 h.[55] The Honeywell MAV incorporates both a forward-looking and downward-looking video camera and is able to hover and continuously monitor a space. The MW Power drone can be fitted with high-resolution still cameras, colour video cameras and infrared night vision cameras. Even micro-drones, such as the SkySeer, can be fitted with video cameras, thermal imaging devices, radiation detectors, mobile-phone jammers and air sampling devices.[56] The cameras on these drones can be so powerful that UASs fitted with electro-optical sensors "can identify an object the size of a milk carton from an altitude of 60,000 feet [18,288 m]".[57] In the future, UASs may also incorporate lethal and non-lethal weapons. Discussing the police force's use of UASs for visual surveillance, an American sheriff in South Carolina stated "We do have the capability of putting a weapon on there if we needed to."[58] Other developments could include weapons such as combustible materials, incapacitating chemicals or explosives being integrated into UAV payloads,[59] or long range acoustic devices that send piercing sounds into crowds, high intensity strobe lights which can cause dizziness, disorientation and loss of balance, tasers that administer an electric shock[60] or tear gas and rubber rounds.[61] Other capabilities could include tagging targets with biological paints or micro-sensors that would enable individuals or vehicles to be tracked from afar.[62]

3.2. *Current and future applications*

UASs have been used, are being used or are actively being considered for different applications in North America, Europe and beyond. While UASs also have a range of potential environmental or commercial applications (emergency response, pollution detection, crop spraying, etc.), they can be deployed in surveillance applications against civilians, such as applications in policing and border surveillance. Like other surveillance devices, UASs often target the "usual suspects", including the poor, people of colour and anti-government protesters. Some police departments in Europe and North America (where data is most available) have been using UASs since 2006. At least five police forces in the UK (Essex, Merseyside, Staffordshire, Derbyshire and the British Transport police) have purchased or used micro-drones, and Los Angeles, Houston and Miami-Dade police (among others) have all used or are considering UASs. The range of potential applications is clear to police forces, where, for example, the "South Coast Partnership" between Kent Police and five other police forces in the UK is seeking to "introduce drones 'into the routine work of the police, border authorities and other government agencies' across the UK".[63]

Police forces use UASs to monitor large crowds, prevent or detect crime and assist in incident responses. UK police have used UASs to monitor festival-goers by "keep[ing] tabs on people thought to be acting suspiciously in car parks and to gather intelligence on individuals in the crowd",[64] to monitor protests at a right-wing festival[65] and to monitor the Olympic handover ceremony at Buckingham Palace.[66] In 2007, drones were reported over political rallies in New York and Washington, DC.[67] The CannaChopper has been deployed in the Netherlands and Switzerland against cannabis smokers, football fans at the European football championship in 2008 and "troublemakers" at the NATO summit in 2009.[68] India has also recently begun using UASs to help secure sensitive sites and events. A popular shrine that is often the target of "anti-social elements" and other security threats may get UAS surveillance.[69] Furthermore, UASs were reportedly given the "go-ahead" to assist Indian security forces in providing surveillance coverage of game venues and residential zones during the 2010 Commonwealth Games.[70]

In addition to large crowd monitoring, UASs have been used to monitor small groups or particular spaces to prevent or detect crime. The Merseyside police force in Liverpool has used two drones to police "public order" and "prevent anti-social behaviour". Police in Liverpool have flown a drone over groups of young people loitering in parks and used it for covert surveillance.[71] German police have been using drones to monitor "alleged hooligans" and urban areas, although Eick reports that Germany is relatively "behind" other western European countries in UAS deployment.

A North Carolina county is using UAVs with infrared cameras to monitor "gatherings of motorcycle riders" and to detect marijuana fields.[72] In this deployment, the UAV flies

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[55] Bowes, op. cit., 2006.

[56] Bowcott Owen, Lewis Paul. Unmanned drones may be used in police surveillance. The Guardian 24 Sept 2010. http://www.guardian.co.uk/uk/2010/sep/24/police-unmanned-surveillance-drones.

[57] The Economist, op. cit., 2007.

[58] WLTX. A.I.R. (Ariel Intelligence and Response) to help law enforcement. 22 Mar 2011. http://www.wltx.com/news/article/129337/2/From-Toy-to-Life-Saving-Tool.

[59] Nevins, op. cit., 2011.

[60] Whitehead John W. Drones over America: tyranny at home. Charlottesville, VA: The Rutherford Institute; 28 June 2010. http://www.rutherford.org/articles_db/commentary.asp?record_id=661.

[61] Ibid.

[62] Nevins, op. cit., 2011 and Randerson, op. cit., 2007.

[63] Ibid.

[64] Randerson, op. cit., 2007.

[65] Hull, op. cit., 2010.

[66] AirRobot UK. AirRobot: the London 2012 Olympics handover ceremony at Buckingham Palace, AirRobot UK News 2008.

[67] Whitehead, op. cit., 2010.

[68] Eick, op. cit., 2009.

[69] IANS [Indo-Asian News Service]. Tirupati temple may get UAV surveillance. Deccan Herald 19 Oct 2010. http://www.deccanherald.com/content/105844/tirupati-temple-may-get-uav.html.

[70] Sarin Ritu. UAVs to provide real-time surveillance during games. Indian Express.com 22 Sept 2010. http://www.indianexpress.com/news/uavs-to-provide-realtime-surveillance-durin/685737/.

[71] Randerson, op. cit., 2007.

[72] McCullagh Declan. Drone aircraft may prowl U.S. skies. CNET News 29 March 2006. http://news.cnet.com/Drone-aircraft-may-prowl-U.S.-skies/2100-11746_3-6055658.html#ixzz1JURmGB4a.

a few hundred feet in the air, which is close enough to identify faces.[73] Six police departments in Canada are using UASs in sparsely populated areas to record crime scenes,[74] and Canadian police are responsible for the first photographs taken by a UAV being admitted as evidence in court after the local police force used a UAV to photograph a homicide scene in 2007.[75] The "South Coast Partnership" mentioned above is seeking to use UASs for maritime surveillance as well as a range of other police issues including surveillance at the 2012 Olympic Games in London.[76] Belgium, France and Italy have used UASs to monitor "undocumented workers, undocumented migrants and demonstrators".[77]

UASs may also be used to assist police in incident response. Merseyside police are credited with the first UK arrest using a drone, where a car thief was tracked through undergrowth by the UASs' thermal imaging camera.[78] Once the teenage suspect's location was detected by the AirRobot flying at 150 feet (45.7 m), the information was relayed to ground forces who arrested the youth.[79] The Netherlands have also used UAVs to "support police in the eviction of a squat"[80]. In Los Angeles, a sheriff's department deployed their SkySeer drone to seek missing persons in rural areas, monitor accident or crime scenes and assist police in pursuits.[81]

UASs have been used in border surveillance operations in the USA since 2002. The US is one of the most well documented users of UASs in this capacity along the US–Mexico border and the US–Canada border. In 2002, a US Marine-operated Pioneer UAV intercepted people who were attempting to smuggle 45 kg of marijuana from Canada into the US.[82] In 2004–2005, UASs were deployed in routine operations along the US–Mexico border. The success of these systems is evidenced by one Predator UAV flying 886 h and assisting officers to capture 2300 undocumented immigrants as well as 3760 kg of marijuana in its first seven months.[83] In 2005, Predator UAVs along Arizona's border with Mexico were integrated into a surveillance system that included seismic sensors, infrared cameras and laser illuminators. If the seismic sensor is triggered by drug smugglers, "the Predator can investigate and, upon finding drug smugglers, tag them with its laser illuminator. With the GPS coordinates and the infrared illuminator, agents have no difficulty intercepting the smugglers".[84] Canadian authorities have also used UASs to patrol smuggling corridors along their border with the USA.[85] Austria also uses UAVs to monitor its borders[86] and Frontex, the European border agency, has held UAV demonstrations, while the UK envisions using UAS for maritime border surveillance.[87]

In the development of new applications, UASs could be used for a variety of new policing functions. Drones could be used for safety inspections, perimeter patrols around prisons and thermal imaging to check for cannabis being grown in roof lofts.[88] The police could use them to capture number plates of speeding drivers.[89] The UK newspaper, *The Guardian*, has identified other deployments including "[detecting] theft from cash machines, preventing theft of tractors…railway monitoring, search and rescue… [and] to combat fly-posting, fly-tipping, abandoned vehicles, abnormal loads, waste management".[90] Mike Heintz of the UNITE Alliance (which represents major companies such as Boeing, Lockheed Martin and Northrop Grumman) stated that further examples of UAS applications "are limited only by our imagination".[91]

This overview demonstrates that while UAS devices have been used in a range of applications, it is the same "usual suspects" who are targeted by UAS surveillance. Eick argues that in Western Europe, there is "hardly a marginalised group that is not targeted by UAVs", and this paper illustrates that this is common to other countries as well. Large crowd monitoring generally focuses on protesters, "hooligans" and "anti-social" elements. The use of UASs to prevent or detect crime through monitoring spaces or small crowds have been deployed against "bikers", groups of young people and undocumented migrants, while UASs which support police in incident response have been used against young people and squatters. Similarly, border surveillance, particularly as used along the US–Mexico border and for maritime surveillance, often have people of colour as their intended targets. As Coleman and McCahill note, surveillance systems often reinforce positions of marginalisation,[92] introducing civil liberties concerns regarding discrimination into deployments of UAS devices. Furthermore, despite the benefits to policing and border surveillance, the use of UAS technology raises safety, ethical and privacy concerns alongside this disproportionate targeting of already marginalised populations.

4. Privacy impacts and ethical issues raised by the technology

While there are clear beneficiaries in relation to the deployment of UASs in civil applications, some academics, civil society organisations and journalists voice significant concerns about their large-scale deployment. Although safety is a significant consideration, the potential for ethical and privacy infringing practices represents a clear threat to civil

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[73] Ibid.

[74] Nevins, op. cit., 2011.

[75] Homeland Security News Wire. Canadian police push limits of civilian UAV laws. 17 Feb 2011. http://homelandsecuritynewswire.com/canadian-police-push-limits-civilian-uavs-laws.

[76] Lewis, op. cit., 2010.

[77] Ibid., p. 4.

[78] Hull, op. cit., 2010.

[79] Lawrence Mark. Setting matters straight. AirRobot UK News 2008. http://www.airrobot-uk.com/air-robot-news.htm.

[80] Ibid., p. 4.

[81] Bowes, op. cit., 2006.

[82] Sia Richard HP. Agencies see homeland security role for surveillance drones. Congress Daily 12 Dec 2002. http://www.govexec.com/dailyfed/1202/121202sia.htm.

[83] McBride, op. cit., 2009. p. 635.

[84] Dunlap, op. cit., 2009. p. 180. See also Matthews, op. cit., 2010.

[85] Nevins, op. cit., 2011.

[86] Eick, op. cit., 2009.

[87] Bowcott and Lewis, op. cit., 2011 and Page, op. cit., 2007.

[88] Bowcott and Lewis, op. cit., 2011.

[89] Whitehead, op. cit., 2010.

[90] Lewis, op. cit., 2010.

[91] McCullagh, op. cit., 2006.

[92] Coleman and McCahill, op. cit., 2011.

liberties. Those who deploy UAS devices appear to be cognisant of these potential civil liberties concerns, where, for example, Lewis finds that police forces in the South Coast partnership sought to stress the "good news story" of UAS maritime surveillance rather than the general usage of UASs in police work to minimise civil liberties concerns and deflect fears about "big brother".[93] However, given that UASs are often deployed against marginalised persons within specific populations, this means that the safety, ethical and privacy issues are far more likely to impact upon and further marginalise these populations.

4.1. *Safety*

Safety is a primary consideration for individuals commenting on the possibility of large-scale deployments of UASs due to issues such as maintenance, pilot error and the potential use of UASs as weapons. Because they are unmanned, UASs may be less well maintained and subsequently less reliable than aircraft which carry persons[94] – the current accident rate for UAVs is 100 times that of manned aircraft.[95] The Electronic Privacy Information Center (EPIC) argues this poor safety record increases risks to commercial aircraft and civilians being monitored.[96] In 2007, the US National Transportation Safety Board (NTSB) reported that pilot error was the cause of an April 2006 Predator B crash, as the team piloting the UAV accidentally turned the engine off.[97] There is also a serious risk that UAVs, particularly as payloads become more sophisticated, could be used as a weapon, as they were in early World War I deployments.[98] For example, despite police interest in using UASs to monitor the 2012 Olympic Games, *The Guardian* reports that the UK Civil Aviation Authority is unlikely to allow UASs so close to large crowds and London City Airport.[99]

4.2. *Ethics*

In addition to safety concerns, there are significant ethical considerations surrounding the use of UASs for surveillance in civil applications. There has been an on-going debate on the ethics of using remotely piloted vehicles in combat operations. They have been blamed for significant losses of life on the ground in combat zones, the removal of soldiers "from the human consequences of their actions".[100] In relation to civil applications, Hayes, of Big Brother Watch, states that "drones and other robotic tools will add to the risks of a Playstation mentality developing along Europe's borders",[101] where bodies are objectified into "things to track, monitor, apprehend, and kill".[102] Hayes further argues that the European Union's security-industrial complex has placed law enforcement demands ahead of civil liberties concerns.[103] Nevins agrees, stating that "the normalization of previously unacceptable levels of policing and… official abuse" has "disturbing implications for civil and human rights". Whitehead concurs, stating that "the logical aim of technologically equipped police who operate as technicians must be control, containment and eventually restriction of freedom".[104] Nevins also reports fears of "mission creep" in police use of UASs.[105]

However, there is some debate about how UASs affect the targets of this distantiated surveillance. Whitehead argues that drones raise civil liberties concerns because "[e]veryone gets monitored, photographed, tracked and targeted".[106] Similarly, Nevins notes that while UASs are seen by law enforcement as "just another tool in the toolbox" and technologically neutral, "[t]here is every reason to be concerned about how the law enforcement and 'homeland security' establishments will take advantage of their new tools".[107] Wall and Monahan argue that in combat situations this distantiation is racialised, where the use of UASs has:

> *harm[ed] ethnic and cultural others with great prejudice…[and] lump[ed] together innocent civilians with enemy combatants, women and children with wanted terrorist leaders. From the sky, differences among people may be less detectable, or—perhaps more accurately—the motivations to make such fine-grained distinctions may be attenuated in the drive to engage the enemy.*[108]

We have already seen evidence that similar racialised marginalisation as well as class, gender and political marginalisation is occurring in relation to UAS surveillance in civil applications. Furthermore, the potential for UASs to carry weapons raises more immediate safety and ethical concerns about the right to life. According to PrisonPlanet.com, the death toll from non-lethal Tasers in the US is more than 350 people,[109] which Wall and Monahan predict could "further the violent dehumanization and non-differentiation" of UAS devices.[110] Thus, despite apparent technological neutrality, the negative ethical impacts of UAS devices are likely to fall disproportionately on marginalised populations.

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[93] Ibid.

[94] Dunlap, op. cit., 2009.

[95] Bolkcom, op. cit., 2004.

[96] EPIC, op. cit., 2005.

[97] The Economist, op. cit., 2007.

[98] Coifman Benjamin, McCord Mark, Mishalani Rabi G, Redmill Keith. Surface transportation surveillance from unmanned aerial vehicles. In: Proceedings of the 83rd annual meeting of the Transportation Research Board; 2004. http://www.ceegs.ohio-state.edu/~coifman/documents/UAV_paper.pdf.

[99] Bowcott and Lewis, op. cit., 2011.

[100] Cronin, op. cit., 2010.

[101] Hayes Ben. Arming big brother: the EU's security research programme, summary of the report. Transnational Institute; April 2006. http://www.tni.org/es/archives/act/4451.

[102] Wall Tyler, Monahan Torin. Surveillance and violence from afar: the politics of drones and liminal security-scapes. Theoretical Criminology 2011;15(3):239–54, 246.

[103] Hayes, op. cit., 2006.

[104] Whitehead, op. cit., 2010.

[105] Nevins, op. cit., 2011.

[106] Whitehead, op. cit., 2010.

[107] Nevins, op. cit., 2011.

[108] Wall and Monahan, op. cit., 2011. p. 243.

[109] Whitehead, op. cit., 2010.

[110] Wall and Monahan, op. cit., 2011. p. 243.

4.3. *Privacy*

Privacy emerges as a key civil liberties concern in relation to the deployment of UASs. Policy-makers and law enforcement agencies have attempted to mitigate concerns about privacy by claiming that UAS devices are no different from a range of existing surveillance systems, such as CCTV or helicopter surveillance. While this may be broadly true, the argument does not address the current complexity of UAS systems which may used like fixed CCTV cameras in some situations or like helicopters in other situations, nor does it address the likely future developments in UAS capabilities or payloads.

Some journalists have relayed worries about the distinct lack of concern about the potential for civil liberties intrusions by UASs. Nevins quotes Stephen Graham, Professor of Cities and Society at Newcastle University, who says that "broader concern about the regulation and control of drone surveillance of British civilian life has been notable by its absence."[111] Evidence from projects on UASs suggests that the focus of web materials, reports and deliverables is on the technical capabilities and potential applications of UASs and they only mention privacy in passing.[112] Similarly, when discussing the revocation of the LA sheriff's licence to deploy UASs, Killam briefly mentions ACLU concerns about the surveillance of private citizens.[113]

Yet some journalists and other stakeholders have made concerted efforts to raise privacy issues in relation to UASs. A report in *The Economist* notes that "UAVs can peek much more easily and cheaply than satellites and fixed cameras can"; they can "hover almost silently above a property" and that "the tiny ones that are coming will be able to fly inside buildings".[114] *The Economist* also quotes an FAA spokesman who stated that "It smacks of Big Brother if every time you look up there's a bug looking at you".[115] EPIC notes that UAVs give the US federal government "a new capability to monitor citizens clandestinely" and states that the costs of these vehicles may outweigh the benefits.[116] Liz Hull of *The Daily Mail* describes UASs as a "worrying extension of Big Brother Britain",[117] while Sia in *Congress Daily* reports that the Senate Armed Services Committee Chairman acknowledged that UASs are "quite intrusive"[118]. Other journalists have noted that specific victims of the mass deployment of UASs in civil air space could be celebrities subject to paparazzi drones.[119]

Some of the consequences of the intrusions of UASs include physical, psychological and social effects. For example, McBride notes that conventional surveillance aircraft, such as helicopters, provide auditory notice that they are approaching and allow a person "to take measures to keep private those activities that they do not wish to expose to public view".[120] McBride opines that the mass deployment of UAS surveillance vehicles which are imperceptible from the ground "could lead to an environment where individuals believe that a UAS is watching them even when no UASs are in operation".[121] This could have a self-disciplining effect, as first described by Bentham and Foucault, where individuals adjust their behaviour as though they were being watched at all times.[122] As a result, "this advancement of surveillance technology threatens to erode society's expectation of privacy, just as the airplane once erased individuals' expectations of privacy in their fenced-in backyards."[123]

Privacy concerns *could* impede the large-scale deployment of UASs, but they face countervailing views. In the US, local law enforcement officials have recognised that privacy concerns represent a stumbling block to the deployment of UASs; however, they have sought to assure the public that "they will not be spied upon by these unmanned drones" and that "this is not [sic] different than what police have been doing with helicopters for years".[124] In LA, police officials reminded citizens that "There's no place in an urban environment that you can go to right now that you're not being looked at with a video camera".[125] While in the UK, senior police officials have argued that "unmanned aircraft are no more intrusive than CCTV cameras and far cheaper to run than helicopters."[126] Similarly, in relation to reports that Google has acquired a UAS, Dillow argues that although "adding an aerial surveillance drone to the mix could stir the ire of privacy advocates", "[i]t's tough to make a case that shooting photos on a public street is an invasion of privacy".[127]

5. Extent to which the existing legal framework addresses the privacy impacts

The numerous, relevant concerns about the safety, ethics and privacy impacts of UASs demonstrate that the use of these devices needs to be regulated. Broadly speaking, few regulations exist for the deployment of UAS surveillance. Part of the difficulty in drawing up regulatory parameters for the use of UASs is that UAVs span an entire spectrum between model aircraft and manned aerial vehicles such as planes and helicopters. Some UAVs are comparable to "large jet-powered machines capable of flying across the Atlantic", while micro-UAVs are more closely related to remotely controlled model aircraft.[128] This means that UAS regulations will likely vary depending on the model, size, weight and speed, making regulations significantly more complex and difficult to

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[111] Nevins, op. cit., 2011.

[112] McCullagh, op. cit., 2006; OPARUS, op. cit., 2010; Nevins, op. cit., 2011.

[113] Killam Tim. US perspective on unmanned aerial vehicles. Institution of Engineering and Technology; 5 Dec 2007.

[114] The Economist, op. cit., 2007.

[115] Ibid.

[116] EPIC, op. cit., 2005.

[117] Hull, op. cit., 2010.

[118] Sia, op. cit., 2002.

[119] Bowcott and Lewis, op. cit., 2011.

[120] McBride, op. cit., 2009. p. 659.

[121] Ibid., p. 661.

[122] Foucault Michel. Discipline and punish: the birth of the prison. New York: Vintage; 1977.

[123] Dunlap, op. cit., 2009. p. 202.

[124] Ibid., p. 182.

[125] Bowes, op. cit., 2006.

[126] Lewis, op. cit., 2010.

[127] Dillow Clay. Google is flying a quadcopter surveillance robot, says drone maker. Popular Science 9 Aug 2010. http://www.popsci.com/technology/article/2010-08/german-spy-drones-maker-sayd-google-testing-quadcopter-surveillance-drone.

[128] The Economist, op. cit., 2007.

understand and enforce. With regard to surveillance, the section above described how many law enforcement organisations have argued that there is no difference between surveillance by UAS and surveillance by other equipment, such as helicopters or CCTV, which police have been using for some time. This section focuses on the tension between the deployment of UAS for law enforcement purposes and the various privacy or data protection regulations with which they may come into conflict. It focuses specifically on case law based on the US Fourth Amendment, EU legislation and UK legislation.

5.1. *The US Fourth amendment*

The Fourth Amendment of the US Constitution protects citizens from unreasonable searches, particularly in areas where individuals have a reasonable expectation of privacy, such as their home or the curtilage (i.e., yard or garden) of their home. Case law has set a precedent where searches are considered unreasonable if a person exhibited a reasonable expectation of privacy, and if that expectation is one which society recognises as reasonable.[129] A US Supreme Court Justice has argued that "a man's home is, for most purposes, a place where he expects privacy, but objects, activities, or statements that he exposes to the 'plain view' of outsiders are not 'protected' because no intention to keep them to himself has been exhibited".[130] As a result, officers have been able to act on information that they gleaned "from naked-eye observations"[131] and "the Fourth Amendment has never required police officers 'to shield their eyes when passing by a home'."[132] This includes material or activities that are visible to the naked eye from aerial vehicles such as helicopters and airplanes, due to the fact that the airways are "public" and that "any member of the public could fly over [a person's] backyard and observe" illegal materials or activity.[133] Furthermore, in *California vs. Ciraolo*, where the defendant was convicted of growing marijuana plants as a result of photographs from an airplane secured by the police, the Supreme Court ruled that the use of a normal 35 mm camera in the operation did not constitute an unreasonable search because it used photographic technology that is "generally available to the public"[134] and the flight itself was judged to be "routine".[135]

However, the opinion of the Court did reflect the possibility that the use of technology which was not generally available to the public might constitute an unreasonable search. For example, the Court stated that "[a]erial observation of curtilage may become invasive, either due to physical intrusiveness or though modern technology which discloses to the senses those intimate associations, objects or activities otherwise imperceptible to police or fellow citizens."[136] Thus, the court ruled that obtaining information about activities inside a home via thermal imaging cameras "constitutes a search – at least where (as here) the technology in question is not in general public use".[137]

Both McBride and Dunlap find that, as long as UASs are not in "general public use", their use for surveillance in places where individuals have a reasonable expectation of privacy would be covered by the Fourth Amendment and the police would be required to obtain a search warrant prior to their use. This is especially true if the UAS incorporates technology such as thermal imaging which is not in "general public use" or if the flights were not considered "routine", for example, if they were flying at non-routine altitudes.[138] However, both point out that if ever UASs are in "general public use", this protection could be nullified. One danger surrounding the general usage principle is that UAVs that could see through "windows or skylights would not constitute a search if the activities or objects inside could be seen with the naked eye" if they were in general use.[139] Furthermore, because electro-optical lenses function similarly to binoculars, telescopes and conventional cameras already used by the public, these sorts of searches could be constitutional even if UASs themselves were not in general public usage.[140] In a similar vein, the courts could argue that UASs are similar enough to helicopters and other methods already used by the police to make surveillance of the area outside the home constitutional.[141]

5.2. *EU legislation and judicial decisions*

In Europe, the use of aerial surveillance technologies is covered by the Charter of Fundamental Rights of the European Union 2000. Article 7 of the Charter of Fundamental Rights states that a person has a right to respect for their private and family life, home and communications, while Article 8 states that an individual has the right to the protection of their personal data. This protection of personal data includes fair processing, consent, access to data and right to rectification. In *Peck vs. the United Kingdom*, the European Court of Human Rights reiterated an understanding that "the monitoring of the actions of an individual in a public place by the use of photographic equipment which does not record the visual data does not, as such, give rise to an interference with the individual's private life", making public space surveillance such as CCTV lawful under the Charter of Fundamental Rights.[142] Under this consideration, UAS surveillance that monitors public space but does not record would be lawful, but surveillance which includes the private home would likely require oversight.

Video surveillance, such as CCTV, which does record falls under the scope of the EU Data Protection Directive of 1995 (95/EC/46). According to the Article 29 Working Party, images or voices are considered to be personal data if they "provide information on an individual by making him/her identifiable

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[129] Dunlap, op. cit., 2009. p. 185.
[130] Ibid.
[131] McBride, op. cit., 2009. p. 627.
[132] Dunlap, op. cit., 2009. p. 186.
[133] Ibid., p. 186–7.
[134] Ibid., p. 189.
[135] McBride, op. cit., 2009.
[136] McBride, op. cit., 2009. p. 649.
[137] Dunlap, op. cit., 2009. p. 195, and McBride, op. cit., 2009. p. 655.
[138] McBride, op. cit., 2009. p. 647.
[139] Dunlap, op. cit., 2009. p. 199.
[140] Ibid.
[141] Ibid.
[142] Williams Victoria. Privacy impact & the social aspects of public surveillance. Covert Policing Review 2008.

even if indirectly".[143] Thus, public space surveillance which records visual data would be considered "personal data" under the Charter of Fundamental Rights and the Data Protection Directive and would mean subjects have rights of consent, access and correction. This is particularly the case after the abolition of the pillar structure of the EC, whereby the original Data Protection Directive did not apply to law enforcement or border protection activities. At present, the abolition of the pillar system means that the way in which the Data Protection Directive now applies to these activities is uncertain. However, if the Data Protection Directive is applicable, individuals in Europe would have the right to access data recorded about them (even indirectly) via a UAS device and they should be given an opportunity to consent to this surveillance.

5.3. *UK legislation*

In the UK, surveillance by UAS devices could be covered by the Data Protection Act 1998 or the Regulation of Investigatory Powers Act (RIPA) 2000. In current deployments of visual surveillance systems such as CCTV, the Data Protection Act 1998 stipulates that, like the EU Data Protection Directive, individuals must be told that a surveillance system is in operation and individuals can request copies of the data the CCTV data controller holds about them.[144] Thus, the Data Protection Act only applies to overt surveillance systems. This could also cover helicopter surveillance, in that helicopter surveillance can be considered overt, due to the noise and visibility of helicopters themselves. However, it would be difficult to inform individuals that UAS surveillance is in operation, particularly as one of the advantages of UAS surveillance is that they are silent and fly at altitudes which make them practically invisible.

In relation to covert surveillance, where the authorities are not obligated to inform individuals that surveillance is taking place, their activities must conform to RIPA. RIPA was enacted to ensure that police investigatory powers were deployed in accordance with the Human Rights Act 1998.[145] RIPA covers both intrusive and directed surveillance, where intrusive surveillance includes surveillance carried out in relation to residential premises or private vehicles and directed surveillance is surveillance that is likely to discover personal information about a target.[146] UAS devices which can hover over homes, can see inside windows and which are fitted with devices such as thermal imaging cameras that may "interfere with a person's private life" would likely need RIPA authorisation in order to be deployed.[147] According to Purdy, RIPA legislation means that large scale, random surveillance of communities or populations using such enhanced UASs would be difficult to justify and are unlikely.

5.4. *Discussion*

This exploration suggests three separate conclusions regarding the current regulation of UAS surveillance. First, this article demonstrates that the complexity of UAS capabilities, available payloads and applications means that a range of laws may apply to the use of UAS devices for surveillance. Some deployments of UASs are similar to CCTV systems or incident response by police helicopter. Because they monitor public space, over-arching regulations like the Charter of Fundamental Rights in the EU or the Data Protection Act in the UK are appropriate to these deployments, as long as the difficulties surrounding consent and access to data can be addressed. However, UAS surveillance that is covert, that uses attachments such as thermal imaging cameras or that is used to monitor private spaces (e.g., a home) would require additional oversight mechanisms, such as search warrants or RIPA approval, in order to be lawfully deployed. Thus, despite Big Brother Watch's call for "stringent, clear, and easily accessible guidelines about how and when these drones can be deployed"[148], such clarity may not be possible given the complexity of these systems.

Second, while current regulations attempt to mitigate some of the privacy issues raised by UAS surveillance, these regulations do not address the other ethical implications of UAS deployment. None of the privacy-focused regulations discussed in this paper adequately addresses the possibilities for social sorting, discrimination or the distantiation effects of UAS surveillance. The Fourth Amendment, the Data Protection Directive and the Data Protection Act do not protect already marginalised individuals and populations from disproportionate surveillance by UAS devices. Furthermore, this legislation does not protect individuals from the "Playstation mentality" of which operators of unmanned aircraft systems have been accused in combat scenarios.

Finally, given the complexity of UASs and the inadequacy of current legal instruments, we find that over-arching legal instruments are not appropriate to protect privacy and other civil liberties in UAS deployments. In the US, McBride has argued that since privacy cannot be adequately protected, the only possible over-arching solution is to consider UAS surveillance "presumptively unconstitutional" because UASs *require* technology to undertake visual surveillance, and the benefits of UASs are specifically associated with high powered cameras, thermal imaging cameras and other sensors.[149] Dunlap states that if they are deployed, administrative measures must accompany legislation, and police departments should be subject to external direction and independent oversight.[150] However, even a legislation combined with oversight may not adequately protect individuals from new

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[143] Article 29 Data Protection Working Party, Opinion 4/2004 on the processing of personal data by means of video surveillance. 11750/02/EN, WP 89; 11 Feb 2004.

[144] Information Commissioners Office. CCTV code of practice. Wilmslow, Cheshire, UK; 2008.

[145] Purdy Ray. The heat is on. The New Law Journal 19 May 2006; 156(7225):1–4, 2. http://www.ucl.ac.uk/laws/environment/satellites/docs/The_heat_is_on156_NLJ_834.pdf.

[146] Home Office. Covert surveillance and property interference revised code of practice; 2010.

[147] Purdy, op. cit., 2006. p. 2.

[148] Sharpe Dylan. Surveillance drone grounded days after 'success'. Big Brother Watch 16 Feb 2010. http://www.bigbrotherwatch.org.uk/home/2010/02/surveillance-drone-grounded-days-after-success.html.

[149] McBride, op. cit., 2009. p. 655.

[150] Dunlap, op. cit., 2009. p. 203.

applications or new capabilities. Instead, a bottom-up mechanism is advocated by Wright et al. who argue that:

> "*today's 'smart surveillance' approaches require explicit privacy assessments in order to sort out the necessity and proportionality of surveillance programmes and policies vis-à-vis privacy.... [I]mprovements are needed in our legal and regulatory framework if privacy is indeed to be respected by law enforcement authorities and intelligence agencies.*"[151]

They assert that one of the primary ways to correct the imbalance between privacy and law enforcement is to explicitly thread privacy considerations through the development and implementation phases of surveillance technology deployment. Such a mechanism may encourage those who deploy UASs for civil applications to focus on what they should do, rather than what they may do. This bottom-up procedure could be combined with a top-down requirement that a privacy or ethical impact assessment must be conducted in order to ensure compliance, whilst simultaneously ensuring that the assessment process is flexible enough and organic enough to address concerns specific to the technological capabilities and deployment procedure under consideration.

6. Conclusion

This consideration of UASs as a "new surveillance" system being introduced for deployment in civil applications has raised significant issues. First, it finds that as a surveillance system, UASs continue a disproportionate attention to the activities of already marginalised populations. Existing divisions such as race, class, political orientation, gender and sexuality are already reflected in current deployments of UASs for policing and border control. Furthermore, the heterogeneity of UAS surveillance devices, capabilities and applications and the way in which many can be deployed covertly, introduce a range of safety, privacy and ethical concerns surrounding their use. We find that these privacy and ethical concerns are not adequately addressed by existing regulatory mechanisms or legislation in the US, EU and UK. Instead, we conclude that multi-layered regulatory mechanisms that combine legislative protections with a bottom-up process of privacy and ethical assessment offer the most comprehensive way to adequately address the complexity and heterogeneity of unmanned aircraft systems and their intended deployments.

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[151] Wright David, Friedewald Michael, Gutwirth Serge, Langheinrich Marc, Mordini Emilio, Bellanova Rocco, et al. Sorting out smart surveillance. Computer Law & Security Review 2010;26(4): 343–54, 344.

A Field Guide to Civilian Drones

By NICK WINGFIELD UPDATED August 29, 2016

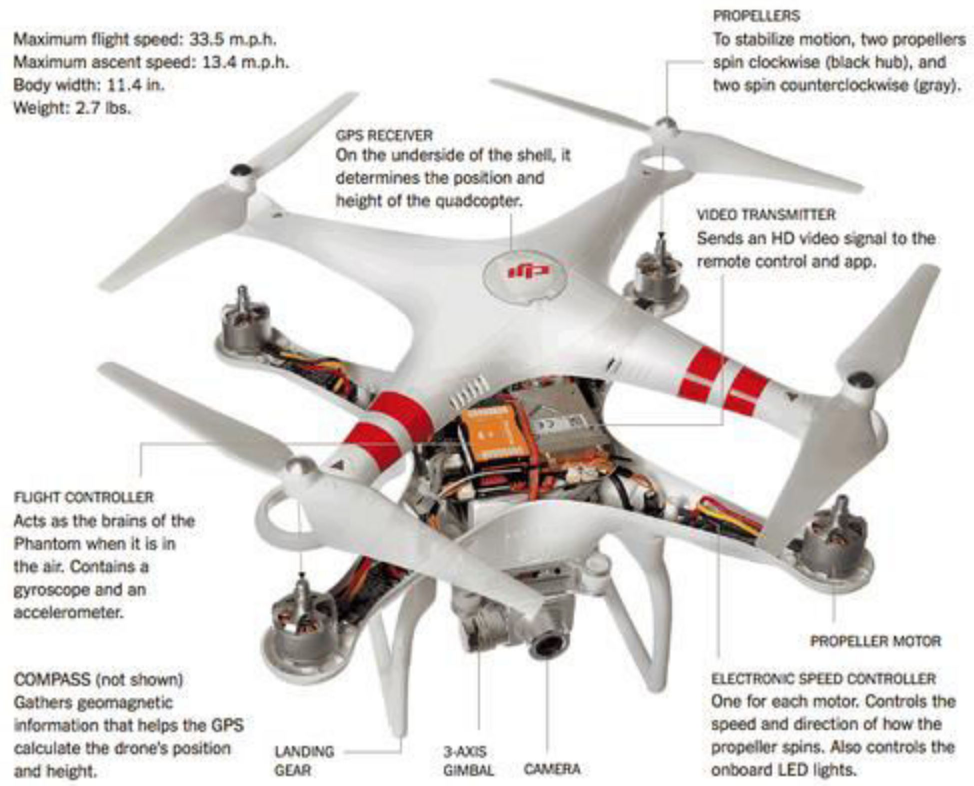
Prepare to see more objects hovering above you. One aviation consulting firm, the Teal Group, estimates that about two million consumer drones, or unmanned aerial vehicles, will be sold worldwide this year alone.

Drones have been used by the military for several years, but as sales of their civilian cousins rise, so do safety concerns among regulators and law enforcement agencies, which worry about everything from drone collisions with airplanes to crashes into crowded stadiums.

The government announced new rules in June that will make it much easier for companies to use drones for commercial purposes, but those rules stop short of allowing for package delivery by drone, which Amazon and Google are both pushing for.

For hobbyists, the Federal Aviation Administration announced rules in late 2015 that require nearly all owners of remote-controlled recreational drones to register in a national database, an attempt by the agency to address safety fears.

Here is what drones will increasingly be up to in the skies:



A Phantom 2 Vision Plus, made by DJI. It has four propellers and comes with a camera that can record high-resolution images and high-definition video. Credit Frank O'Connell/The New York Times; Photos by Tony Cenicola/The New York Times; Source: DJI Technologies

What Exactly Are Drones?

Drones, also known as unmanned aerial vehicles or unmanned aircraft systems, are more advanced versions of the model airplanes hobbyists have flown for decades. They come in airplane and helicopter varieties, sometimes with eight or more spinning rotors. While drones are typically piloted from the ground by a human with a radio controller, many are also capable of autonomous flight along programmed coordinates.

How Many Drones Are Out There?

It’s tough to get a precise estimate of drone sales because most manufacturers are private companies. But one lobbying group, the Consumer Technology Association, says drone unit sales and revenues are expected to double this year. The group expects 2.8 million consumer drones will be sold in the United States in 2016 and revenue will reach $953 million. Globally, sales of drones are projected to reach 9.4 million units in 2016 and revenue is expected to reach $3 billion, the group says.

Drone racing is a fast-growing extreme sport in which pilots compete head-to-head with small flying drones while wearing first-person-view goggles. Credit Video by By ERIK OLSEN on Publish Date November 11, 2015

How Can Drones Be Used?

Some hobbyists buy drones for the sheer joy and challenge of flying an object in the sky, but the biggest thrill for many is capturing spectacular high-quality photographs and video from an aerial vantage point.

For those interested in drones for commercial purposes, the government in June announced rules that make it much easier for companies to use drones for a variety of tasks, including aerial photography and emergency response.

The rules stop short of allowing for package delivery, a goal of Amazon and Google.

The demand by companies for permission to use drones has been broad, including from the real estate industry, news organizations, farmers and emergency responders.

What Risks Do They Pose?

One of the biggest safety concerns about drones is that they could collide with aircraft, endangering passengers and pilots. Drones capturing aerial footage of wildfires have hindered efforts by helicopter and airplane pilots to put out the blazes. The flying vehicles have crashed near spectators at crowded events like the United States Open and a football game. There are also concerns about use of drones to violate privacy and to smuggle weapons, drugs and other contraband into prisons. Some drone makers like DJI are developing software that will prevent people from piloting their drones into restricted airspace.

How Is the Government Regulating Them?

New rules governing commercial drone use announced by the Federal Aviation Administration in June allow a broad range of businesses to use drones under 55 pounds, but with several restrictions: The drones must be operated by a pilot who has passed a written test and is at least 16 years old. The drones can only be flown below 400 feet, during the day, and at least five miles away from airports.

The rules, which went into effect Aug. 29, stop short of allowing for package delivery, a goal of Amazon and Google, which have pushed the F.A.A. to create rules that would allow them to transfer much of their ground-based delivery system to the sky. But experts say the government’s action brings that vision one step closer to reality.

Under rules announced in December 2015, nearly all owners of remote-controlled recreational drones are required to register in a national database. Drone owners are required to submit their names, home addresses and email addresses with the F.A.A., disclosures meant to nudge users to be more responsible, officials said.

States, meanwhile, have been busy passing their own regulations. Twenty states have passed tighter restrictions on consumer drones, banning them in parks, neighborhoods and over churches and schools, for example. The new city and state laws have set up potential clashes with the F.A.A., which has warned local regulators that any new law should go through the agency.