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Planning for walking and cycling in an autonomous-vehicle future

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ABSTRACT

Over the last few decades, walking and cycling have increased in the United States, especially in large cities. Future efforts to promote active travel will occur during a time when automated vehicles will increasingly perform driving tasks without human input. Little is known about impacts of an automated vehicle fleet on pedestrians and cyclists.

This study uses semi-structured interviews with experts from academia as well as the public and private sectors in the United States to (1) explore potential synergies and conflicts between increasingly automated motorized vehicles and active travel; and (2) highlight planning and policy priorities for active travel in a time of emerging connected and automated vehicles (C/AVs).

Our interviews indicate that while C/AVs promise to make roadways safer for motorists, cyclists, and pedestrians, some potential hazards exist related to communication, behavior, and technical capabilities in the near term. In the long-term, C/AVs may have drastic impacts on infrastructure, the built environment, and land use, but these impacts are likely to vary by locality. Federal and state governments will play a role in ensuring that connected and automated vehicles operate safely, but local governments will ultimately determine how automated vehicles are integrated into the transportation network.

1. Introduction

Over the last two decades, walking and cycling (active travel) have increased in the United States—in particular in large cities (Buehler and Pucher, 2019). Efforts to further promote active travel will occur during a time when increasingly automated vehicles will perform more and more driving tasks without human input. The U.S. Department of Transportation's Strategic Agenda (The U.S. Department of Transportation, 2017) has identified walking and cycling as important elements of connected vehicle research. So far little is known about the implications of an increasingly automated vehicle fleet on pedestrians and cyclists. One key factor is the unknown speed of technology development and transition towards automated and connected vehicles (Zmud et al., 2015). This uncertainty results in a wide range of potential impacts on active travel, ranging from safer walking and cycling due to the elimination of human driver error to reduced safety during the transition period towards automated vehicles due to driver over-reliance on still developing technology.

The term "automated vehicle" (AV) refers to a range of vehicles with varying technological capabilities. The vehicles use sensing, network analysis, recognition algorithms, and machine/fleet learning to take responsibility of some, or all, driving tasks from human drivers (Frisoni et al., 2016; Sandt and Owens, 2017; SAE International, 2014). Separate, but related, to vehicle automation is the notion of vehicle connectivity. Strictly speaking, AVs can operate using only in-vehicle sensors and technologies to detect, interpret, and travel through their environment. Connected vehicles (CVs), on the other hand, utilize vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), or vehicle-to-anything (V2X) communication to relay such information as presence, speed, direction of travel, braking, signal phase and timing, and road and traffic conditions (Krechmer et al., 2016). While there is no consensus as to the exact time frame of development or market saturation of autonomous vehicles, most academics and industry watchers agree that fully autonomous vehicles are unlikely to constitute a majority of the vehicle fleet until 2040 at the earliest (Litman, 2017; Mosquet et al., 2015). Thus, drivers, pedestrians, and cyclists will have to maneuver in an environment with vehicles of varying levels of automation for decades to come.

This study uses semi-structured interviews with experts from academia as well as the public and private sectors in the United States to (1) explore potential synergies and conflicts between increasingly automated

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motorized vehicles and active travel; and (2) highlight planning and policy priorities for promoting active travel in a time of emerging automated and connected vehicles (C/AVs). The next section provides a concise literature review focusing on automated vehicles and active travel. Next, a methods section provides an overview of our research approach. The remainder of this paper is devoted to the description and analysis of interviewee responses to questions asked during semi-structured interviews.

2. Literature review: C/AV deployment, pedestrians, and cyclists

To understand the implications of C/AV deployment for pedestrians and cyclists, and to formulate our interview questions, we reviewed the literature to assess the current state of knowledge. We searched the Transportation Research Board's TRID database and Google Scholar using the terms "automated vehicle", "pedestrian", "cyclist", "bicyclist", "bicycling", and filtered out the results that were not relevant to our research focus. Results varied between academic, peer-reviewed journal articles, academic and government reports, and articles from professional association publications. We then expanded our selection of literature with sources cited in our original findings. Much of the literature on C/AVs and pedestrians/cyclists touches on four primary categories: 1) the built environment and infrastructure, 2) technology, 3) social and behavioral issues, and 4) the role of the public and private sectors.

Most studies assessing the built environment and C/AVs do not focus on cyclists or pedestrians and envision that all or most vehicles on roadways drive autonomously. The literature suggests that C/AVs could ultimately bring about changes to the built environment that both positively and negatively affect pedestrians and cyclists. For instance, experts predict that more efficient use of roadways, narrower car-travel lanes, and less on-street parking may open up more space for bike lanes or pedestrian amenities (Krechmer et al., 2016; Alessandrini et al., 2015; Chapin et al., 2017). On the flip side, the lower cost of automobile travel may lead to more suburban sprawl, with trip distances too long to cover by active travel, and to C/AVs replacing trips previously taken by foot, bike, or transit (Litman, 2017; Cavoli et al., 2017). Millard-Ball (2016) posits that to facilitate widespread C/AV use, newly installed physical barriers may have to prevent pedestrians from freely walking in front of C/AVs.

Technology plays a central role when discussing C/AVs, as all of the other effects ultimately stem from its operation, how it is perceived, and how people react to it. Blanco et al. (2016) find that the Google car experienced a rate of 5.6 less-serious crashes per million miles, as compared to the rate of 14.4 for human drivers. In their extensive literature review, Cavoli et al. (2017) identify cybersecurity as a potential threat to C/AVs, both in terms of protected user data, but also in preventing bad actors from hacking and misusing C/AVs—which could pose a great danger to pedestrians and cyclists. Vissers et al. (2016) find that many difficulties remain for the detection of cyclists and pedestrians by AVs. Inclement weather reduces the effectiveness of sensors, and the software still has difficulty in anticipating the actions of cyclists and pedestrians. They also note that AVs do not currently possess the means to communicate with other road users the same way as a driver would. Moreover, in both partially- and highly-automated vehicles, driver re-engagement becomes more difficult when more drivers are engrossed in a non-driving task (Cavoli et al., 2017).

Studies on behavioral and social ramifications of C/AVs face methodological difficulties, because survey respondents may not have a clear conceptual understanding of C/AVs. Deb et al. (2018) find that respondents that show greater openness towards C/AVs are more likely to cross in front of them. Respondents that exhibited rule-abiding pedestrian behaviors, such as obeying traffic rules, trust C/AVs more than those who flout traffic rules. Similarly, Cavoli et al. (2017) find that cyclists and pedestrians may trust C/AVs more than they trust human drivers, as long as C/AVs are reliable and programmed to behave safely. Habibovic et al. (2016) and Lundgren et al. (2017) suggest that if eye contact is not a possibility with C/AVs, then vehicles must be designed to communicate their intentions to pedestrians using an external interface.

Millard-Ball (2016) hypothesizes that autonomous vehicles will prioritize the safety of vulnerable road users over traffic flow. As a result, active travelers would receive all of the benefits of C/AVs and would interrupt traffic flow, while the technology is rendered increasingly unattractive to drivers. Drivers themselves may come to rely too much on their C/AVs' abilities as well. Harper et al. (2016) posits that drivers risk an "enhanced immunity fallacy", where they maintain a false sense of security and exhibit unsafe behaviors.

Most C/AV policy research envisions localities, states, and the federal government playing different roles in the deployment of C/AVs, and in the protection of vulnerable road users. On the national level, Harper et al. (2016) determined, given the massive potential safety and economic benefits of fleet-wide adoption of crash avoidance systems that constitute low-level AV technologies, that the federal government may step in and require all new automobiles to include such technologies. Chapin et al. (2017) primarily consider the ways that cities would have to adapt their infrastructure to accommodate autonomous vehicles, and to recognize the role urban planners play in this process. They call for planners to educate themselves on the technology, incorporate C/AVs into long-range plans, develop new infrastructure standards, rethink parking, and identify development opportunities. Similarly, the U.S. Department of Transportation has published documents that assert that the responsibility for implementing some pedestrian safety technologies and applications rests with metropolitan planning organizations (MPOs) (Krechmer et al., 2016). Bierstedt et al. (2014) believe that it is too early for localities to consider C/AVs in their long-range plans, but that they must remain mindful of pedestrian and cyclist safety.

The potential of increased safety is the primary promise of C/AVs. But while optimists guarantee a reduction in automobile crashes, if C/AV technology encourages vehicle travel over active travel, it may lead to further-reaching negative outcomes for public health through reduced physical activity and the negative health effects of increased emissions and climate change (De Hartog et al., 2010). The confluence of factors from the four areas discussed above - technology, behavior, the built environment and infrastructure, and the role that the public-sector – will ultimately determine how C/AVs affect the safety and health of motorists, cyclists, and pedestrians.

Indeed, there are potential traffic safety problems specific to the interaction between C/AVs and pedestrians and cyclists (Sandt and Owens, 2017; NACTO, 2017). PBIC (Sandt and Owens, 2017) provides the most exhaustive summary of C/AV and active travel safety issues to date. The report finds that current C/AV detection rates for pedestrians and cyclists are much lower than for other vehicles. This problem partly stems from pedestrians and cyclists not wearing detectable electronic beacons as well as poor location accuracy of V2X technology, particularly in dense urban areas. In addition, several detection systems partly rely on built environment characteristics (such as crosswalks or bike lanes) to predict the presence of cyclists or pedestrians—while in reality C/AVs may encounter pedestrians in many locations. Moreover, current technology has difficulty predicting future movements and intent of pedestrians and cyclists.

PBIC (Sandt and Owens, 2017) also identified other conflicts unique to pedestrians and cyclists. For example, C/AVs used for commercial ridesharing or deliveries require frequent access to curb-space where they typically interact with pedestrians and cyclists—traversing bike lanes or even sidewalks to deliver passengers and/or goods. Moreover, traffic laws, culture, and expectations vary across U.S. locations for passing distance while overtaking a cyclist as well as for yielding to pedestrians at crosswalks. Given the current limitations in human-machine communication, it is unclear how C/AVs will adapt to and communicate in these situations with pedestrians and cyclists.

3. Data and methods

This study uses semi-structured interviews of experts in academia, industry, and government in the United States to assess the state of knowledge and key issues for bike and pedestrian planning during C/AV deployment. Semi-structured interviews are a qualitative research method designed to explore topics for which quantitative data are difficult to collect and conceptual constructs are still developing (Galletta, 2013) — in this case to obtain in-depth information on the interviewees' knowledge, thoughts, and reasoning regarding the effects of an increasingly automated vehicle fleet on walking and cycling. The interviews were conducted by phone, and responses were summarized and coded by theme using notes taken for each interview. The analysis examines themes that emerged from the interviews, including instances of disagreement among experts.

The semi-structured interviews include a set of predefined open-ended interview questions. Drawing on topics identified in the literature review, the questions are related to the anticipated different phases of automation; safety; government regulation; as well as built environment and roadway space requirements (see Fig. 1).

First, our team of researchers identified a range of experts, balancing among academia, the public sector, and the private sector. Experts were also balanced between walking/biking experts and C/AV experts, with a few people having expertise in both areas. Initial sets of potential interviewees were identified among members of the TRB committees for pedestrians, bicycling as well as their sub-committees, recent publications/reports, and speakers at conferences on the topic. Other existing contacts of research team members helped identify C/AV and/or active travel experts from academia as well as the public and private sectors. During interviews, the research team also employed "snowball sampling" asking respondents to identify other potential respondents knowledgeable in the area of walking, cycling, and automated vehicles. Table 1 shows the information of interviewees', area of expertise, and sector types.

The researchers emailed interview invitations to candidate participants asking for participation in 40–45 min phone interviews. Confirmed interviewees received a list of the semi-structured interview questions about two weeks prior to the actual interview. The project was classified as 'exempt' by Virginia Tech's Institutional Review Board (FWA00000572; 18-064). Interviewers kept extensive notes during the interviews using a standard form to record all notes. The same interviewer led all interviews. The semi-structured format of the interviews allowed the interviewer to ask for clarification, follow-up questions, or probe answers. If questions emerged or remained after the interview or in the process of summarizing the interview, interviewees were contacted for follow-up questions.

Once an interview was completed, each interview was summarized combining interview notes from different note takers. After all interviews were finished, we analyzed our notes using the following process: First, the notes for all interviews were read together and then individually one-by-one. Second, when reading the interview notes, the researchers highlighted relevant pieces of information with labels—a process called coding or indexing. At this stage items were labeled if they were (a) repeated by different interviewees, (b) identified as crucial by interviewees, or (c) could be connected to themes previously identified in the literature. Third, these labels were brought together into categories and their connection, and underlying patterns were identified.

In the results section we present these categories of information provided by the interviewees. Thus, the results section typically provides

Table 1
Interview participants by expertise and employment sector.

Interviewee ID	Expertise	Sector
1	Urban sprawl, C/AVs, car ownership, VMT/GHG reduction	Academia
2	Engineer, pedestrian expert	Public sector
3	Electric car company representative	Private sector
4	Pedestrian/bicyclist expert, planning	Academia
5	Architecture and design	Academia
6	Chief Marketing Officer of an autonomous vehicle company	Private sector
7	Engineer, pedestrian/bicyclist expert	Public sector
8	C/AVs, roadway pricing, Greenhouse Gas (GHG) emissions, travel demand, traffic safety	Academia
9	Engineering	Academia
10	C/AVs	Public sector
11	Environment, economy, equity in transport systems	Academia
12	C/AVs, travel behavior analysis, impacts of new technologies	Academia
13	Pedestrian/Bicyclist Safety	Academia
14	Sustainability and transportation	Academia
15	Vulnerable road users, safety, and engineering	Academia

		Expertise	
		C/AV	Pedestrians/bicyclists
Sector	Academia	5	7
	Public sector	1	3
	Private sector	2	0

Impact on Pedestrians and Bicyclists

- Q1. What, if any, impacts do you expect C/AVs to have on pedestrians and cyclists in the next 40 years? Generally, do you expect widespread adoption of C/AVs to positively or negatively impact pedestrians and cyclists? Why?
- Q2. What challenges do you see for the interaction of C/AVs with pedestrians/cyclist?
- Q3. What would you identify as key milestones in C/AV technology and deployment, as they relate to pedestrians and cyclists?

Solution

- Q4. What should be priorities for local, regional, state, federal law makers and planners guiding the transition to C/AVs as it relates to ped/bike?
- Q5. Who should bike/ped planners work with in anticipation of the transition?
- Q6. When and how should ped/bike planners start to get involved?

Fig. 1. Interview questions.

information that was provided by multiple interviewees. On occasion, we also highlight non-typical responses/opinions by individual respondents within the categories identified. These instances are clearly identified in the analysis.

4. Results and discussion

4.1. Potential impact of C/AV deployment on pedestrians and cyclists

Interview subjects were asked what impacts C/AVs will have on cyclists and pedestrians over the course of the next four decades, and whether they envision those impacts to be positive or negative. Respondents agreed, that planning, policies, and standards may go a long way towards mitigating any potential negative effects for pedestrians and cyclists, but it remains uncertain as to how planners and policymakers will accommodate C/AVs.

A majority of respondents expressed a belief that local policies will affect how cyclists and pedestrians are impacted by C/AVs. If local decision makers prioritize the comfort and safety of cyclists and pedestrians, then C/AVs can have an overall positive effect. On the other hand, in places where deference is given to automobiles, cyclists and pedestrians may lose ground. Most respondents predicted that cities will continue along their current trajectories; i.e. those that devote resources to accommodate and encourage a range of travel modes will continue to do so, while those that cater nearly exclusively to automobiles will maintain their priorities. Aside from expecting different scenarios in different localities, a few respondents said that we should expect different impacts at different levels of technological development and market uptake. Policy, technological capabilities, and market adoption will all determine the overall impacts of C/AVs on pedestrians and cyclists and at different times and places.

In general, respondents expressed agreement over the positive impacts on pedestrians and cyclists likely to occur from C/AV adoption. A majority of interviewees expected C/AV technology to be safer and more reliable than human drivers. Some interviewees mentioned that another safety advantage of C/AVs is that they believe bikes and pedestrians will be able to predict highly automated vehicle behavior better than they can predict the behavior of human drivers. While many respondents expressed concern for current detection and prediction capability of C/AVs, they were optimistic that such hurdles would be overcome eventually. Nearly all interviewees stated that C/AVs will or must prove that they are at least as safe as human-driven automobiles. Some noted that given the number of traffic fatalities every year in the U.S., that safety standards should be substantially higher for C/AVs (than just at least as safe as human drivers).

Aside from the potential safety benefits from a technological standpoint, interviewees said that if the hypothetical space saved on roadways were to be converted to bike-lanes or pedestrian paths, the increased mode separation would help to protect pedestrians and cyclists. A few respondents suggested that transport modes should be separated further to smooth the flow of traffic. Improved safety for cyclists and pedestrians would only be an ancillary outcome of that scenario.

The most commonly predicted negative effects of C/AVs on cyclists and pedestrians include safety concerns during the transitional period, increased regulation of bicyclist and pedestrian behavior, and less active travel due to the greater attractiveness of car travel. The most commonly expressed concern pertained to gaps in knowledge and expectations of C/AV abilities, both on the part of the driver and other road users. During the transitional period as C/AVs become more commonplace, drivers, cyclists, and pedestrians may overestimate the cars' abilities. Pedestrians and cyclists may have a difficult time differentiating C/AVs from traditional automobiles, and new norms of interaction may have to be developed. Transparency in testing and data may be necessary for the public to form reasonable expectations of how the technologies perform.

Roadway engineering strategies for accommodating C/AVs and nonmotorized modes were only mentioned by a few interviewees with differing perspectives on the appropriate level of separation between C/AVs and pedestrians. A C/AV industry representative stated that, in order to minimize conflicts between C/AVs and pedestrians, a high degree of separation would be ideal, specifically using the example of Las Vegas Boulevard in Las Vegas, Nevada, a roadway where pedestrians are completely separated from vehicles with bridges and fencing. A pedestrian and bicycle researcher independently anticipated that C/AV implementation may lead to demands for increased separation between vehicles and nonmotorized modes. However, he arrived at the opposite conclusion, stating that bike/ped advocates should fight to prevent increased separation. Enforcement and education strategies for addressing C/AV conflicts with walking and bicycling were not raised by our respondents.

Interviewees also worried bicyclists and pedestrians may be required to carry beacons to enable C/AVs to recognize them more easily. While such a measure could increase safety, interviewees expressed equity and privacy concerns. Some of the experts interviewed for this study also expected that active travel could be reduced further by making driving more convenient. Given the widely-recognized health benefits of active travel, negative health outcomes could result from a mode shift away from walking and biking and towards C/AV use.

In general, interview subjects held positive beliefs about the long-term safety implications of C/AV technology for cyclists and pedestrians. This is in spite of near-term concerns that the technology cannot accurately detect cyclists and pedestrians and predict their movement accurately enough.

4.2. Challenges for the interaction of C/AVs with pedestrians and cyclists

When asked what challenges they foresee in how C/AVs interact with pedestrians and cyclists, interviewee responses fell into five categories: cyclist and pedestrian behavior and expectations of C/AVs; C/AV behavior and decision-making; the technical capabilities of C/AVs; communication; and infrastructure as a mediator or cause of conflicts.

Nearly half of the interview subjects identified a few ways that pedestrian and cyclist behavior may come into conflict with C/AVs. One of the primary conflicts highlighted is that if C/AVs become commonplace, easily identifiable, and prioritize cyclists and pedestrian safety, cyclists and pedestrians may alter their behavior on roadways. This would contribute to the unpredictability of cyclists and pedestrians. Moreover, if they no longer have to worry about being hit, cyclists and pedestrians may use public rights-of-way (ROW) more assertively than today, slowing down motorized traffic. One respondent – citing the CityMobil2 project – suggested that if this does happen, the behavior would likely die out quickly. In the localities where CityMobil2 operated, people would jump or walk out in front of the AV at the outset of the pilot projects, but resumed giving deference to the vehicle after the initial stages of the project. This suggests, as one other respondent noted, that there may be a period when both machines and humans are simultaneously learning of each other's behavior and adjusting accordingly.

Some respondents stated that conflicts between C/AVs and cyclists/pedestrians depend on how automotive companies will program C/AV behavior in relation to the law and to the comfort of vulnerable roadway users (VRUs). One interviewee asserted that C/AVs will obey the law, yet another raised the point that AVs today, like Tesla automobiles, allow users to exceed speed limits while using automated systems. Even if C/AVs are required to follow all traffic laws, one interviewee stated that norms and laws differ in some instances. For example, in some places automobiles are only required to give cyclists 2 ft of leeway when passing. A space many cyclists might find uncomfortable, especially at higher speeds. In those cases, it is unclear if C/AVs will simply meet minimum legal standards for behavior, or if they will give cyclists a wide berth to maintain comfort.

Most respondents identified conflicts that may arise from inadequate technical capabilities of C/AVs. Chiefly, the detection rate of cyclists is still too low. Even if cyclists are detected, C/AVs do not yet have the data or processing power to accurately predict pedestrian and cyclist movement, which is often more sudden and unpredictable than automobile movement. C/AVs often use an array of sensor technologies to detect their environment. Some respondents expressed concern that detection rates for cyclists and pedestrians at night – for systems that rely heavily on visual recognition – are too low. Others noted that inclement weather can occlude many types of sensors, and that C/AVs may not yet safely function when there is heavy rain or snow or any other dangerous weather conditions. While these problems exist in current technology, most interviewees expressed optimism that the shortcomings would be overcome in the near future, and no respondent indicated that they think these technological hurdles are insurmountable. Rather, they mostly pose a problem in the near term.

Nearly half of the interview respondents raised the issue of communication between C/AVs and cyclists and pedestrians. Without a human driver that can use eye contact and physical gestures to communicate with other roadway users, cyclists and pedestrians may not understand what a C/AV's intentions are. They also may not know whether or not a C/AV has identified them. One respondent proposed that C/AVs should use a visual form of communication, possibly even face-like symbols, to communicate with other roadway users. Another suggested that audible communication may work, but only if there are few other AVs on the road so as to prevent a cacophony of unintelligible warnings. However, it will be difficult for individual pedestrians and cyclists to discern if AV audio and visual signals are meant for them or not. While most interviewees discussed the lack of C/AVs ability to communicate, a few noted that pedestrians do not typically use hand gestures to indicate turns, which makes them more difficult to predict. One said that, at present, C/AVs have difficulty understanding body language and hand gestures of roadway users, indicated that at present barriers exist for communication both ways.

For the issues outlined above, infrastructure may mitigate or exacerbate conflicts. How cities plan for vulnerable road users and vehicles to share the roadway and how they prioritize the movement of traffic will be important. A few respondents noted that mode separation between C/AVs and cyclists would be ideal, at least while C/AVs cannot consistently identify active travelers and predict their movements. Intersections may need to be redesigned for C/AVs, but this could ultimately be detrimental for pedestrians and cyclists if the redesign prioritizes vehicle throughput over the needs of all users.

The points of conflicts that interviewees foresee are not necessarily intractable. Some challenges may be overcome by further technological development being undertaken by the automotive industry, others by changes in roadway infrastructure, and others as a natural result of behavioral change on the part of C/AVs and people. Because C/AVs are not yet widespread, it is still unclear which conflicts may or may not materialize. As many of the interviewees stated, substantial variability will exist in how localities plan for C/AVs. Some places will trend more towards increased mode separation in an attempt to ameliorate conflict, while others will take a different approach and use the expected safety benefits to further integrate travel modes.

4.3. Milestones in C/AV development for pedestrians and cyclists

Nearly half of the interviewees stated that the development of safety standards for C/AVs will be an important and necessary step for the widespread deployment of C/AVs. Before setting operational standards, regulators must first decide what metrics will be used to formulate those standards. A majority of interviewees mentioned accurate detection and prediction rates of cyclists and pedestrians as a milestone. Among respondents though, there was a split between those who think that the yardstick that C/AVs should be measured against are human drivers, or whether new standards and acceptable costs/risks should be more stringent and specifically decided upon for C/AVs. Some respondents specified that testing should be carried out under a range of conditions to ensure adequate detection and prediction of cyclists and pedestrians at night and in inclement weather conditions. Respondents were consistently clear, though, that C/AVs detection and prediction of pedestrians and cyclists is not satisfactory at present.

Some respondents mentioned policy and regulatory milestones related to C/AV testing and prioritization of transportation modes. While there was little consensus among all respondents as to what these milestones would consist of, some broad themes on connectivity/communication and testing emerged.

Regarding connectivity and communication, one interviewee asserted that bicyclists and pedestrians should carry beacons that transmit basic information to nearby C/AVs and suggested using V2I and adaptive signals to monitor pedestrian build-up at crosswalks. Another questioned whether or not dedicated short-range communication (DSRC) will be antiquated by the time 5G wireless systems are widely available. Lastly, one respondent stated that standards would have to be developed for communications between C/AVs and other roadway users. These milestones clearly relate to some of the points of conflict between C/AVs and cyclists/pedestrians, i.e., no two-way communication or inadequate detection and prediction.

Interviewees also stressed the importance of testing. One respondent said a major milestone would be every state in the United States allowing C/AV testing. By doing so, policymakers and planners in those states will have a better understanding of how they will operate within the specific context of their jurisdiction. As of the writing of this paper, all testing is carried out by first parties (i.e. manufacturers or operators of AVs). Some interviewees said that they would like to see third party testing, perhaps by National Highways Traffic Safety Administration (NHTSA). One interviewee opined that C/AV manufacturers may not be testing their cars in more difficult environments. More extensive use of pilot projects, policies permitting the testing of C/AVs on public roads, and third-party testing could help expand the public knowledge of what C/AVs are capable of and how to plan for them.

4.4. Priorities for local, regional, state, and federal lawmakers and planners

Most interviewees held the opinion that there should be some degree of government regulation of C/AV technologies. As mentioned previously, an integral part of the government's role when it comes to C/AVs is establishing testing criteria or safety standards for detection, prediction, and behavior. Some interviewees mentioned other technological standards that they believed the federal government should establish. Among those are V2X communication and cybersecurity standards. Lastly, a few interviewees suggested that at some point the federal government may mandate C/AV technologies in all new cars, as it has with other technologies in the past, e.g. ESC, ABS, or seatbelts. Only one respondent further distinguished that policies or regulations vis-à-vis technology should vary based on level of automation. Only one interview subject believed that government regulations were unnecessary, suggesting instead that the level of liability automobile manufacturers would be subject to in the instance of C/AV collisions would be sufficient to encourage C/AV manufacturers to ensure that their products are road-worthy before selling them. Another interviewee directly challenged this line of thinking. Long supply chains with parts from different OEMs interacting with third-party software in a vehicle with an operator all obscure who the directly responsible party is in a collision, unless precedent is set that automotive manufacturers are, without question, liable for crashes.

For state and federal policies and regulations, the most common responses advised that state governments should not preempt localities in implementing policies and regulations for C/AVs, and that some data transparency requirements should be implemented. As already discussed extensively, most interviewees had a difficult time making concrete predictions because in their view, cities would decide how they would accommodate C/AVs based on local priorities. State preemption would do away with this flexibility. One respondent noted that state DOTs also have a history of prioritizing automotive transportation as compared to other modes. Some respondents strongly encouraged governments to require that C/AVs share travel and safety data with them in exchange for permitting their use of public ROW. The technological standards discussed previously would be established and upheld by federal and/or state authorities. Lastly, some respondents speculated that state and federal lawmakers may need to reconsider their taxation regimes in the face of changing travel behaviors (i.e. moving away from the gas tax towards distance, time, vehicle occupancy, or area based taxes). In summary, most respondents viewed the role of federal and state governments as regulators of C/AV technology, otherwise the interviewees believed that state governments should stay out of the way of local decision makers.

As for local policies, interviewees were unable to provide many concrete examples of what should be done. A recurring theme among many answers was that localities should prioritize accessibility over vehicle throughput by prioritizing bicyclist and pedestrian needs over C/AVs. A few respondents suggested that cities would also need to rethink their sources of revenue related to vehicles, especially municipally owned parking. As part of this reworking of local revenues, one respondent said that local governments should consider taxes to discourage certain behaviors, e.g., taxing empty C/AVs travelling on public ROW. Finally, some respondents stressed that local governments will need to raise awareness of C/AVs and their impacts during the transitionary period. In general, their responses seemed to suggest that whereas the state and federal governments filled the role of the regulator, local governments would make decisions of infrastructure investment, land use, and design that impact C/AVs, cyclists, and pedestrians.

While respondents envisioned local, state, and federal governments fulfilling different roles, a few respondents stressed the need for coordination in the face of implementing new policies and regulations for C/AVs—not just between levels of government, but between government, the public, industry, and advocacy organizations. Many stressed a need to place the public well-being first, but noted that coordination can ensure that expertise and goals of various parties are taken into account as public policies and regulations are developed.

4.5. Who should pedestrian and bike planners work with?

Given the uncertainty of the impacts of C/AVs, the potential conflicts, and the possible need for regulation of C/AVs, interviewees were asked whom they think bike and pedestrian planners should work with in anticipation of a transition to C/AVs. In response, the experts suggested a number of people or groups that planners should work with, most of which can be categorized as industry experts, members of the public, and elected officials and policymakers. Given the far-reaching implications of C/AV technology, it is clear that the responsibility of dealing with its many impacts on cyclists and pedestrians is not solely the responsibility of bike and pedestrian planners.

More respondents highlighted the need for bike and pedestrian planners to work with "industry," i.e., vehicle manufacturers and technology companies, over any other groups. The most frequent response given about working with industry is simply educational. Planners should understand the technology – how it works, what it is capable of, its relevance to their area of practice – before they can start planning for C/AVs. Working with C/AV companies, some experts reported, is key to gaining in-depth knowledge about these technologies.

Whereas this is a more passive role for planners, some respondents suggested that bike and pedestrians planners take a more proactive approach to partnerships. One reason some respondents cited for planners to work with industry is because industry already dominates the process and receives no guidance or oversight by entities representing the public interest. Interestingly, even a respondent from a C/AV technology firm held this viewpoint. Without bike and pedestrian planners proactively seeking the dialogue, automotive companies may not even be aware of the interests of cyclists and pedestrians and how they stand to be impacted by C/AVs.

Related to the previous point of not allowing industry to dominate plans, policy, and discourse, some interview subjects from a wide variety of backgrounds also stressed the importance of connecting with the public. Generally, respondents both stated the need for planners to educate the public about what C/AV deployment means, and for planners to ascertain community goals regarding transportation options. As part of the public outreach and educational role, one interviewee emphasized the need for communicating with the media. Aside from communicating with members of the public as individuals or as a single monolithic collective, there is also room for collaboration with public interest groups representing specific populations.

A majority of interview respondents also identified elected officials and other policymakers as a key group to work with in anticipation of a transition to C/AVs. Because there are many different potential impacts on cyclists and pedestrians outside of the traditional domain of bicycling and walking, planners will have to proactively engage with policymakers to ensure that the interests of cyclists and pedestrians are heard and taken into account. Outreach should also include traffic engineers, economic development planners, council members, legislators, and regulators. Many of the policy and regulatory milestones that the experts proposed (see previous section) are not generally under the purview of bike and pedestrian planners, despite the evident impact on those forms of transportation. These collaborations can of course occur with different officials in the same government, but standards of practice among transportation policymakers and planners across many jurisdictions may also need to be developed. One respondent set forth that the National Association of City Transportation Officials (NACTO) as an example of this, noting that it had already produced some guidance on preparing for C/AVs.

One interview subject stated that bike and pedestrian planners should not be involved in preparing for C/AVs. While they were the only one that expressed this opinion, it appears indicative of how far reaching the effects of the technology could be. Its implications for bike and pedestrian travel constitute only a small part of how C/AVs may change our cities.

4.6. How should pedestrian and bike planners get involved?

Although many of the interviewees touched on planning practices and policies that could be implemented to ameliorate any conflicts that C/AVs may introduce, most did not discuss concrete steps that bike and pedestrian planners specifically could take.

Most commonly, interviewees suggested that planners should start educating themselves on the capabilities of C/AV technologies, how it is currently being used and deployed, and its potential implications for cyclists and pedestrians. Most respondents appeared to believe that the average bike and pedestrian planner possesses limited knowledge on the subject. Before planners can start collaborating with the parties that respondents identified in the previous question, they must first attain a basic understanding of the subject. By doing so they can better communicate with stakeholders and other transportation experts, but they can also begin to envision and plan for the localized consequences of widespread C/AV adoption.

C/AVs may introduce the need to reconsider street design. Earlier in the interview, respondents identified that the behavior of pedestrians, cyclists, and C/AVs could lead to conflict between those modes of transportation. Recognizing the environment's role affecting the behavior for cyclists, pedestrians, and C/AVs will be important. As one interviewee said – signs and laws do not produce behavior, environment does. Among the changes in street design and infrastructure that interviewees mentioned are shared streets, pavement markings, traffic lights, intersection design, lane width, and protective barriers may all need to be rethought. Most respondents did not address how these may need to change or not change during a transitionary, mixed-fleet period. One interviewee noted that, in spite of prolific predictions to the contrary, lane width will not be reduced after C/AVs become commonplace. It would take nearly universal adoption of C/AVs over traditional automobiles before any savings in roadway space could be found.

Given that many of the interviewees foresaw demand reductions both in roadway capacity and parking supply, it's unsurprising that some respondents highlighted this as an area that planners should focus on. In particular, interviewees responded that localities should reconsider issuing bonds to pay for parking facilities. They also suggested that cities engage in scenario planning. In other words, if parking demand drops by a certain amount in an area, on-street parking can be repurposed for another use. New, adaptive uses may also have to be considered for above- and below-ground parking structures. If cities rely on parking revenue for funding municipal priorities, changes to local taxation policies may be in order.

Most interviewees already covered how they think planners should engage with others outside of the profession to enact plans and policies that consider the priorities of cyclists and pedestrians. Chief among their concerns in response to this question was that the discussion around C/AVs has centered entirely around automobiles and how to cater to them, potentially to the detriment of other modes of transportation. Planners will need to advocate for cyclists and pedestrians to industry so that C/AV firms are forced to take into account other roadway users. Respondents also expressed that policymakers and regulators are being courted by the C/AV industry, so it may be the place of the bike and pedestrian planner to offer a counter-narrative.

Overall, the experts suggested that bike and pedestrian planners need to start getting involved with, or deepening their understanding of, C/AVs in the near-term. From there, they should consider how changes to street design can ameliorate conflict and protection of vulnerable roadway users. If the space savings that many predict are realized – an outcome that is not a foregone conclusion – planners will need to begin thinking about how to repurpose ROW and parking. Finally, respondents suggested that planners must, by engaging with policymakers and elected officials, not let C/AV firms dictate the terms of a transition to automation.

5. Conclusions: the role of policy and planning

The general expectation of our interviewees was that C/AV technology will result in safer travel both for the vehicles' occupants and for other roadway users. But some hurdles stand in the way of achieving the desired safety outcomes. In this study, all levels of government were identified as being responsible for different aspects of C/AV and pedestrian and cyclist interactions.

Most respondents stated the need for third party testing and approval of C/AVs to ensure that they can safely operate on the public ROW. Specifically, respondents said that the federal government, likely the NHTSA, should promulgate standards for detection and prediction of cyclists and pedestrians, and develop test routines to ensure that C/AVs meet those standards. It may also be necessary for the federal government to set standards for connectivity between vehicles, infrastructure, and others. Notably, few respondents mentioned regulations on C/AV behavior. Most assumed that C/AVs will obey the law, despite evidence that current low-level AVs knowingly operate over the speed limit.

States will also be responsible for any changes to design and construction of highways and related infrastructure. According to most respondents, ideally states will be very hands-off. They should permit C/AV testing to ensure safer operation. Otherwise, most interviewees said that states should not preempt local governments from implementing C/AV policies and plans that serve local goals. Most respondents held the opinion that C/AV companies should be required to share travel data gathered on public ROW with local, state, and federal governments. Such data could be valuable for transportation planning efforts and for documenting automobile crash statistics.

While state and federal government roles center around creating standards for and regulation of C/AV technology, local governments will be responsible for sidewalk, street, and intersection design that all play a role in ensuring the safe operation of C/AVs in relation to cyclists and pedestrians. Additionally, C/AVs may rely on well-marked roadways for safe navigation, for most local streets maintaining adequate markings is the responsibility of the local government. It is likely that there will be a variety of practices implemented across the United States.

While many of the respondents expressed hope that localities that have traditionally catered to automobiles could reorient themselves to have a more inclusive transportation portfolio, they expect that “business as usual” will continue in most places, with perhaps exaggerated effects. Cities that rely primarily on automobiles to transport their residents may find that their residents are willing to travel further if they do not have to take into account the cost of time spent driving, resulting in increased sprawl. On the other hand, those that invest more in transit, walking, and cycling will continue to rely on a diverse set of transportation options.

Bike and pedestrian planners will play an important role in facilitating this transition, but they will only be one of many actors. Elected officials, real estate developers, and the automobile and mobility industries, will all play a role in how localities grapple with C/AV and their impacts on cyclists and pedestrians. Almost every interviewee stated that bike and pedestrian planners should either begin planning for C/AVs now, or should have already. At present, the planner's primary responsibility is to educate themselves, elected officials, city departments, and the public on the limitations, capabilities, and potential impacts of C/AVs in their communities. In the end, this will produce good planning practices and allow planners to better communicate with the public. Bike and pedestrian planners will also need to engage with industry, elected officials, other planners, and the media to ensure that cyclist and pedestrian concerns and priorities are taken into account in technological development and in the public decision-making process.

Government agencies and many professional groups have already created information clearinghouses, working groups, and initial voluntary guidance documents to inform stakeholder about the transition towards more C/AVs. These include, among others, the Institute of Transportation Engineers (ITE), the American Association of State Highway and Transportation Officials (AASHTO), the American Planning Association (APA), the National Association of City Transportation Officials (NACTO), the Pedestrian and Bicycle Information Center (PBIC), and the United States Department of Transportation (USDOT). Moreover, the Federal Highway Administration (FHWA) announced that the next revision of the Manual on Uniform Traffic Control Devices (MUTCD) would include the needs of C/AVs. However, most of the documents we reviewed did not focus on the needs of pedestrians and cyclists—with the exception of reports by NACTO and PBIC cited earlier. Most typically, the needs of pedestrians and cyclists are highlighted related to prioritizing safety, but not throughout the documents.

Some interviewees, particularly those specializing in technology and automotive transport, discussed the need for mode separation so that cyclists and pedestrians do not impede the flow of traffic and cause safety concerns. Examples include separation by grade and fences or banning cyclists and pedestrians from certain intersections altogether. Some of the pedestrian experts expressed concern about these types of “solutions,” which may restrict the freedom of active travelers and cut them off from the public ROW. On the other hand, planning and policy experts expressed some optimism that the promised advancements in safety will allow for shared roadways to become more prevalent. As with the other policies discussed in this paper, it is likely that different regions or even different localities within a metropolitan area will pursue varying strategies. The diversity of responses in how active travelers should interface with C/AVs underscores the importance of improved communication among planners, industry, researchers, and the public, seeking a consensus on what the future of walking and cycling should be in an automated, connected future.

Most interviewees and currently available voluntary guidelines on the transition towards more C/AVs prioritize safety of all users. However, safety can be accomplished in various ways, ranging from physical separation of active travelers to not interfere with CA/Vs to requiring C/AVs to be fully able to detect and predict all pedestrian and cyclist behavior prior to allowing C/AV deployment. Several respondents suggested that cities should set strategic priorities for transportation and land use. These priorities should be formulated independently of technology—and focus on the communities' vision is for the future. CA/Vs and other technological innovations should then be integrated in this overall strategic vision. For example, a city could decide to prioritize livability and active travel. Such a city would then allow deployment of C/AVs as long as they further that goal. In essence, the suggestion is to not allow technology to set the strategic agenda, but to employ technology to achieve strategic goals.

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Erratum regarding missing declaration of competing interest statements in previously published articles

A **Declaration of Competing Interest** statements were not included in the published version of the following articles that appeared in previous issues of Transportation Research Interdisciplinary Perspectives.

The appropriate Declaration/Competing Interest statements, provided by the Authors, are included below.

1. "Evaluation on the coordinated development of air logistics in Beijing-Tianjin-Hebei" [Transportation Research Interdisciplinary Perspectives, 2019; 1: 100034]
2. "Progress or regress on gender equality: The case study of selected transport STEM careers and their vocational education and training in Japan" [Transportation Research Interdisciplinary Perspectives, 2019; 1: 100009]
3. "What passengers really want: Assessing the value of rail innovation to improve experiences" [Transportation Research Interdisciplinary Perspectives, 2019; 1: 100014]
4. "Audio on the go: The effect of audio cues on memory in driving" [Transportation Research Interdisciplinary Perspectives, 2019; 1: 100004]
5. "Michigan's public transportation: An application of statewide performance assessment and management" [Transportation Research Interdisciplinary Perspectives, 2019; 1: 100013]
6. "Planning for walking and cycling in an autonomous-vehicle future" [Transportation Research Interdisciplinary Perspectives, 2019; 1: 100012]
7. "Are you going to get a ticket or a warning for speeding? An autologistic regression analysis in Burlington, VT" [Transportation Research Interdisciplinary Perspectives, 2019; 1: 100001]
8. "Physical activity of electric bicycle users compared to conventional bicycle users and non-cyclists: Insights based on health and transport data from an online survey in seven European cities" [Transportation Research Interdisciplinary Perspectives, 2019; 1: 100017]
9. "An informal transportation as a feeder of the rapid transit system. Spatial analysis of the e-bike taxi service in Shenzhen, China" [Transportation Research Interdisciplinary Perspectives, 2019; 1: 100002]
10. "Modeling bus passenger boarding/alighting times: A stochastic approach" [Transportation Research Interdisciplinary Perspectives, 2019; 2: 100027]
11. "Disaggregation of aggregate GPS-based cycling data – How to enrich commercial cycling data sets for detailed cycling behaviour analysis" [Transportation Research Interdisciplinary Perspectives, 2019; 2: 100041]
12. "Reducing global warming by airline contrail avoidance: A case study of annual benefits for the contiguous United States" [Transportation Research Interdisciplinary Perspectives, 2019; 2: 100033]
13. "Effect of social capital on the life satisfaction of paratransit drivers in Sri Lanka" [Transportation Research Interdisciplinary Perspectives, 2019; 2: 100050]
14. "To drive or not to drive? A qualitative comparison of car ownership and transport experiences in London and Singapore" [Transportation Research Interdisciplinary Perspectives, 2019; 2: 100030]
15. "Incorporating systems thinking approach in a multilevel framework for human-centered crash analysis" [Transportation Research Interdisciplinary Perspectives, 2019; 2: 100031]

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