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FINAL REPORT

Planning for Walking and Cycling in an Autonomous-Vehicle Future

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Over the last few decades, walking and cycling have increased in the United States, especially in large cities. 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. Little is known about impacts of an increasingly automated vehicle fleet on pedestrians and cyclists. This study uses semi-structured interviews with experts from academia as well as public and private sectors to:
(1) explore potential synergies and conflicts between increasingly automated motorized vehicles and active travel;
(2) highlight planning and policy priorities for promoting active travel in a time of emerging automated and connected vehicles;
(3) identify areas of future research on planning for active travel in an automated vehicle future.

While C/AVs promise to make roadways safer for motorists, cyclists, and pedestrians, some potential hazards exist related to communication, behavior, 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. The federal and state governments will likely play a role in ensuring that connected and automated vehicles operate safely, but local governments will likely determine how automated vehicles are integrated into the transportation network. This study also examines when and how bicycle and pedestrian planners should get involved in planning for C/AVs, and who they should work with.</td></tr>
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1. Introduction

Over the last two decades walking and cycling (active travel) have increased in the United States—in particular in large cities (Pucher, Buehler, & Seinen, 2011). 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. Little is known about impacts 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, Tooley, Baker, & Wagner, 2015). For example, possible impacts include safer walking and cycling due to elimination of human driver error to reduced safety during the transition period towards automated vehicles due to driver over-reliance on limited and still developing technology. The U.S. Department of Transportation's Strategic Agenda (S30 in that report) has identified pedestrian and cycling as important elements of connected vehicle research. This study uses semi-structured interviews with experts from academia as well as public and private sectors to:

(1) explore potential synergies and conflicts between increasingly automated motorized vehicles and active travel;

(2) highlight planning and policy priorities for promoting active travel in a time of emerging automated and connected vehicles;

(3) identify areas of future research on planning for active travel in an automated vehicle future.

The next section provides a short introduction to automated and connected vehicles. This is followed by a literature review focusing on automated vehicles and active travel. Next, a methods section provides a short overview of our research approach. The remainder of this report is devoted to the summary/analysis of interviewee responses to eight key questions asked during semi-structured interviews.

2. Background: Automated and Connected Vehicles

2.1 What are Automated and Connected Vehicles?

The term "automated vehicle" (AV) refers to a whole range of vehicles with varying technological capabilities. The vehicles use remote 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 & Owens, 2017). The Society of Automotive Engineers' six-tiered taxonomy of AVs has widely been adopted as the standard system of classifying the level of automation for automobiles (see Table 1) (SAE International, 2014).

Table 3. Levels of Vehicle Automation According to the Society of Automotive Engineers

SAE Level	Name	Definition
0	No Automation	the full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems
1	Driver Assistance	the driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task
2	Partial Automation	the driving mode-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task
3	Conditional Automation	the driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene
4	High Automation	the driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene
5	Full Automation	the full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver

Source: SAE International, 2014

Separate, but related, to vehicle automation is the notion of vehicle connectivity. Strictly speaking, AVs depend only on onboard sensors to detect and interpret 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). V2X capability may mean communication with pedestrians via handheld electronics such as smart phones. Despite the possible applications of CV technologies, it is not entirely clear whether they are necessary for highly automated vehicle (HAVs) – vehicles between SAE automation levels 3 and 5 (Anderson et al., 2014; Sandt & Owens, 2017).

2.2 Current Technology and Future Development

Several major automobile manufacturers anticipate selling level 3 AVs as soon as 2020 (Lavieri et al., 2017). Some manufacturers, claim that they will release a fully autonomous vehicle in 2025. However, some expect that technology, infrastructure, and regulatory framework will take at least 20 years to mature enough for level 5 AVs to become widespread (Frisoni et al., 2016). While there is no consensus as to the exact time frame of 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). As a consequence, even if fully autonomous vehicles are available for consumer purchase by 2025, autonomous vehicles will operate in a fleet composed of a mix of manually driven, partially-automated, and fully-automated vehicles for decades to come. The rate of adoption will likely depend on the pace of technological advancement, consumer preferences and willingness to pay, cost of AVs, vehicle ownership trends, and government regulation. For example, Bansal & Kockelman (2017) predict that 24%-87% of the U.S. vehicle fleet will consist of C/AVs by 2045. The Boston Consulting Group sets forth a number of scenarios for AV adoption, the slowest of which anticipates a range of 20%-43% of new car sales to consist of C/AVs by 2040. (Mosquet et al., 2015) The Victoria Transport Policy Institute (VTPI) anticipates 30% of the fleet will be composed of AVs and 50% of new car sales in the 2040s (Litman, 2017).

Regardless of exact time frame, highly automated vehicles will not substitute existing vehicles overnight; drivers, pedestrians, and cyclist will have to maneuver in an environment with vehicles of varying levels of automation for decades to come. This has implications for how vehicles interact with one another, especially depending on how effectively the human-machine interface between highly automated vehicles (HAVs) and humans communicates intentions.

2.3 Why AVs?

Predictions of the advent of automated vehicles (AVs) date at least as far back as Norman Bel Geddes' and General Motors' 1939 New York World's Fair exhibit, "Futurama" (Geddes, 1940; General Motors, 1940). In his 1940 book *Magic Motorways*, Bel Geddes (1940) observed that "as long as there is an opportunity to make a mistake, some driver will make it." Seeing the limits of human drivers, he proposed making roadways safer by removing the human factor from driving to the greatest extent possible. Although Bel Geddes's prediction of widespread automated vehicles by 1960 never materialized, automobile manufacturers have sought to develop AVs chiefly for the same reasons he described in 1940, including safety (Alliance of Automobile Manufacturers, 2018; Karrberg, 2017). But, we have come to associate a host of other costs with driving, related to tailpipe emissions, congestion, time spent driving, and land use, that manufacturers, policy makers, and academics believe AVs may ameliorate.

2.4 Market: Shared or Private Ownership?

If C/AVs come to be widely used, there are two diverging scenarios related to their ownership and use. Personal vehicle ownership may continue as the norm, or we may observe a shift toward shared vehicles and mobility-as-a-service (MaaS) (C/AVoli et al., 2017). The personal ownership scenario represents a continuation of the status quo, while under the second scenario few people would own private cars. Motorists would instead rely on businesses that resemble taxi and transportation network companies (TNCs) with automobiles owned and maintained by companies, summoned on-demand, and shared between passengers (C/AVoli et al., 2017). This shift towards shared mobility may not happen everywhere or all at once. Just as today, more densely populated areas may cater more naturally to the TNC or MaaS models while private ownership may dominate in rural and exurban locales. Similar to today, shared autonomous vehicles (SAVs) will likely be used only in situations where they offer substantial savings in time or money to users.

There is uncertainty about impacts of SAVs on mode choice. On the one hand, SAVs could lead to greater integration with public transport, by providing last-mile service and filling in service gaps. On the other hand, increased reliance on SAVs may also result in decreased transit ridership (C/AVoli et al., 2017; Litman, 2017). Recent research by Clewlow and Mishra (2017) suggests that around half of TNC trips made in the United States replace trips that would have otherwise been made by biking, walking, and transit. Additionally, TNC users reported reduced transit use. Given that the shared mobility scenario envisions C/AVs being used in similar businesses models to today's TNCs, such findings seem to predict that the shared mobility scenario, instead of encouraging biking and walking, will increase the mode share of automobiles.

2.5 Changes in the Built Environment

C/AVs are expected to influence the built environment, but because any major alterations to the built environment would be preceded by widespread market uptake of AVs, major changes to the built environment will not play out in the short-term (Krechmer et al., 2016). Like many of the expected impacts of widespread C/AV adoption, there are divergent possibilities and little certainty regarding outcomes. Predictions that favor cyclists and pedestrians include the need for less land devoted to downtown parking and narrower, more efficiently used travel lanes. Some propose that the extra space (no longer needed for parking) could be used for bicycle and pedestrian infrastructure (C/AVoli et al., 2017; Krechmer et al., 2016). Conversely, because AVs promise to decrease the cost of driving, both in terms of fuel efficiency and the opportunity cost of operating a car, people may tolerate longer commutes, leading to resurgent urban sprawl, greater VMT, and more automobile dependency (C/AVoli et al., 2017). Detection technology that already exists in some low-level AVs today uses lane markings to determine the automobile's position (Gordon & Lidberg, 2015). Widespread C/AV use may require a local governments and state DOTs to commit additional resources to maintaining roadway markings.

2.6 Natural Environment

Some envision that C/AVs will drastically reduce emissions. A few factors have been suggested for this. First, by drafting behind one another in long trains, or "platooning", automobiles will reduce their aerodynamic drag and increase fuel efficiency. If this increases vehicle throughput without a corresponding increase in VMTs, it could reduce fuel wasted due to congestion. In order for this to be feasible, it may be necessary for lanes to be dedicated solely to HAV use, so manually driven vehicles do not disrupt the platoon, and that automobiles be connected through direct short-range communication (DSRC). To ensure that traditional automobiles do not use dedicated HAV lanes, additional barriers may need to be put in place.

Second, safety features of present-day automobiles account for a significant amount of their weight. If the safety promises of HAVs hold true, 'old-fashioned' safety features could be replaced by automation technology made with lighter materials. But much like human drivers, AVs will be no less subject to other irresponsible drivers; thus this would require near universal adoption of HAVs (Anderson et al., 2014).

Third, automobiles could accelerate and decelerate more efficiently than human drivers do, in what has been termed "eco-driving" (Anderson et al., 2014). As mentioned previously, lower driving costs could exacerbate suburban sprawl, leading to more vehicle miles traveled and destruction of ecosystems for further development.

On the other hand, some preliminary studies suggest that the availability of AVs may induce travel, leading to increased VMTs (Harb et al., 2017). It still remains unclear how travel behaviors will change and if the vision of AV optimists will be realized.

3. 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 performed a literature review 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. Using these terms, we found 19 results addressing the impacts of C/AVs on cyclists and pedestrians. 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 AVs and pedestrians/cyclists touches on four primary categories: 1.) the built environment and infrastructure; 2.) technology, 3.) social and behavioral issues, 4.) the role of the public and private sectors.

3.1 Built Environment and Infrastructure

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 (Alessandrini et al., 2015; Krechmer et al., 2016). On the flip side, lower cost of automobile travel may lead to more suburban sprawl and to AVs replacing trips previously taken by foot, bike, or transit (C/AVoli et al., 2017; Litman, 2017). While, the focus in most studies assessing the built environment and AVs, was not specifically on cyclists and pedestrians, there are clear consequences for active travel from land use. Urban land freed from parking could be used to make cities more livable for pedestrians and cyclists. On the other hand, increased automobile-oriented sprawl could make cycling and walking less viable—because of longer trip distances and more motorized traffic.

Millard-Ball (2016) focuses on behavioral impacts of widely-used fully autonomous vehicles. He posits that we must adapt the built environment and infrastructure to the behavioral changes cyclists and pedestrians are likely to undergo. For instance, to facilitate wide-spread C/AV use and prevent pedestrians from freely walking in front of C/AVs, Millard-Ball suggests that cities place physical barriers between sidewalks and roadways and require that all crosswalks be marked.

Chapin, et al. (2017), identified five major areas of impact of AVs on the built environment: roadway design, signage and signalization, bike and pedestrian networks, drop-off zones, and parking. But, like many authors, the urban environment they envision assumes all or most vehicles on roadways drive autonomously. They note, as others have, that narrowed travel lanes for automobiles could free-up space for more extensive bike and pedestrian networks, but that mode separation may be necessary to ensure the free flow of traffic.

Many of the predicted changes in the built environment would only be reasonable if most or all of the vehicles on the roadway are connected and automated. There seems to be little research about how infrastructure and the built environment can facilitate the transition towards increasingly automated vehicles, and mediate conflicts between a mixed fleet of vehicles and vulnerable roadway users.

3.2 Technology

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. Thus, researchers and market-watchers have assessed the current state of the technology, and technology's immediate, safety-related impacts. Blanco et al. (2016) examine the current state of technology by comparing recent crash data from Google's self-driving cars with naturalistic crash data – ranked by severity of incident – on human-driven vehicles.[1] Their research could not show with confidence that Google's Self-Driving Car avoided more-serious crashes than human-driven automobiles. However, it did find that the Google car experienced a rate of 5.6 less-serious crashes (of any severity) per million miles, as compared to the rate of 14.4 per million miles for human drivers. Considering that these less serious crashes occur overwhelmingly in urban areas, where pedestrians and cyclists are more likely to be, better crash avoidance in low-speed, urban areas could result in fewer cyclists and pedestrian injuries and fatalities.

Further exploring the safety benefits of AVs, Harper et al. (2016) examined how the safety impacts of three AV/crash avoidance technologies translate to economic effects. They found that in the instance of fleet-wide implementation of three crash avoidance technologies – Forward Collision Warning (FCW), Lane Departure Warning (LDW), and Blind Spot Monitoring (BSM) – on light duty vehicles, the U.S. could expect a net annual benefit of between $18 billion and $202 billion in avoided crash costs.[2] Notably, the authors mention that this excludes benefits from averted cyclists and pedestrian injuries and fatalities.

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[1] Comparing the two presents some difficulty, because reporting requirements for AV related crashes differ between states. State governments also often impose different crash reporting requirements for AVs than manually-driven vehicles. Blanco and Perez attempt to solve this problem by determining how many crashes go unreported to police, how the difference between reporting Google Self-Driving Car accidents and manually-driven car accidents is affected by the percentage of unreported crashes and severity, and how street type and speed impacts crash rates. They found that at least 60 percent of crashes that resulted in property damage only were not reported to the police, although this number falls to 25 percent for those that result in personal injury.

[2] The low-end is based on current crash statistics for vehicles equipped with DCW, LDW, and BSM, while the upper bound assumes all crashes are prevented. This study underlines the huge potential safety benefits of low-level AV

In their extensive literature review, C/AVoli et al. (2017) consider technology issues raised by hardware, software, and data. They identified cybersecurity as a potential threat to market uptake of C/AVs, both in terms of protected user data, but also in preventing bad actors from hacking and misusing C/AVs. Whether controlled by a human or a computer program, automobiles driven carelessly or maliciously still pose a great danger to pedestrians and cyclists, who would be most vulnerable to such attacks.

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. In addition, there is no solution for the 'handoff problem' – mainly relevant for automation level 3 and the gap between passing control of the vehicle from the computer to the human driver. Vissers et al. found that, given both the vulnerability of cyclists and pedestrians and the difficulty detecting them, cyclists and pedestrians generally exhibited a cautious attitude toward AVs. Finally, they note that AVs do not currently possess the means to communicate with other road users as a driver would. Such technology is prerequisite for AVs to gain widespread acceptance. Similarly, Sandt and Owens (2017) identify 10 areas where C/AV technology does not yet sufficiently protect pedestrians and cyclists. Among the problems they identify, accurate and consistent detection of cyclists and pedestrians remains out of reach, while V2X technology has not matured to a reliable point.

3.3 Social and Behavioral Issues

A number of authors have studied the behavioral and social ramifications of C/AVs, as well as on the public's receptivity of C/AVs. Because only low-level C/AV's are available on the market at present, these studies face methodological difficulties. For example, survey respondents may not have a clear conceptual understanding of C/AVs, may not take into account other implications of C/AVs besides the technology when formulating their opinion, and have not had the opportunity to use C/AVs.

Deb, et al. (2018) administered an online stated-preference questionnaire to gauge pedestrian receptivity of fully autonomous vehicles (FAVs) using three subscales of safety, compatibility, and expected interactions. They then posed different scenarios and asked how respondents would behave as a pedestrian when confronted with an AV. They found that respondents that showed greater openness toward FAVs were more likely to cross in front of them. Respondents that exhibited positive pedestrian behaviors, such as obeying traffic rules, trusted FAVs more than those who flouted traffic rules. Deb, et al.'s model may prove useful in a study of how perceptions influence revealed pedestrian behaviors vis-à-vis C/AVs.

Non-drivers may turn to AV use if AVs are popular and convenient (C/AVoli et al., 2017). Because of this, C/AVoli et al. (2017) and Harb et al. (2017) found that C/AVs could lead to an increase in vehicle miles travelled (VMT) as they gain market share. They also discuss

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technologies. The dollar amount is drawn from insurance claim payouts. Their calculations assume that insurance claim payouts cover the entire cost of car crashes reflect the true cost of car crashes. The authors do also assume a social cost of $162,400 per crash, although they never make clear the source of this statistic.

different rollout scenarios. The first, “business-as-usual”, predicts continued personal car ownership, increased personal automobile use, and declining transit ridership. The second, “shared mobility”, would result in new ownership models with C/AVs supplementing or integrating with transit, and C/AV users sharing automobiles with other passengers.

As discussed earlier, fully-automated vehicles will not be available to consumers for some time, and market saturation would likely take decades after their initial introduction into the market. During this time, a combination of manually-driven, partially-automated, and fully-automated vehicles will operate on roadways. In both partially- and highly-automated vehicles, driver re-engagement has been well-studied. The literature has generally found that it becomes more difficult for drivers to reengage the more they are engrossed in a non-driving task. But engaging in those non-driving tasks is core to what people find attractive in AVs (C/AVoli et al., 2017).

Regarding AV and cyclist/pedestrian interaction, C/AVoli, et al. (2017) found that cyclists and pedestrians may trust AVs more than they trust human drivers, as long as AVs are reliable and programmed to behave safely. Habibovic, et al. (2016) and Lundgren, et al. (2017) report on the same “Wizard of Oz” experiment that the authors used to make a manually driven vehicle “appear” autonomous. They accomplished this by 1.) hiding the steering wheel in the right-hand passengers seat, and having the driver act distracted; or 2.) leaving the driver’s seat empty altogether, with the actual driver posing as a passenger. Test subjects were then accompanied on a walking route by an observer. Along their route they would encounter manually driven vehicles, and the two scenarios mentioned above, while an observer recorded the interaction. Results show that pedestrians were less likely to cross the street in front of an inattentive driver, but eye contact between the driver and pedestrian led to “calm interactions.” The authors suggest that if eye contact is not a possibility with AVs, then vehicles must be designed to communicate their intentions to pedestrians using an external interface. This study raises the importance of developing an effective human-machine interface to mediate interactions between AVs and other road users.

Millard-Ball (2016) considers how pedestrian – not driver – behavior would change due to C/AVs. He posits that whenever pedestrians choose whether or not to cross the street, they make a calculation on the likelihood of an automobile maiming or killing them. He examines the current state of theory and knowledge on pedestrian and motorist interactions and then predicts how the model of road user behavior will change as a result of widely adopted AVs. In the scenario he puts forth, autonomous vehicles prioritize the safety of vulnerable road users (VRUs) over traffic flow. As a result, pedestrians receive all of the benefits of AVs while the technology is rendered increasingly unattractive to drivers. In the end, he foresees three possible futures: 1.) pedestrians “reign supreme”; 2.) changes to urban design, regulatory regimes, and enforcement seek to counteract more assertive pedestrian behavior; 3.) human-driven cars remain popular, given the susceptibility of trip delay due to pedestrians. He acknowledges that the behavioral shift he describes is predicated on widespread adoption of fully autonomous vehicles, so if autonomous vehicles do give rise to such scenarios, it would be decades in the future. In their more broadly focused report, Vissers, et al. (2016) also broach the subject of pedestrian and cyclist behavior changing much in the same way that Millard-Ball has here, although they also reference some studies that assert that, at present, pedestrians and cyclists do not trust AVs any more than human drivers.

Drivers themselves may come to rely too much in their AVs' abilities as well. Harper (2016) posits a scenario where, as AV technology starts to improve safety, drivers risk an "enhanced immunity fallacy", where they maintain a false sense of security and exhibit unsafe behaviors.

3.4 Role of the Public Sector

Some envision localities, states, and the federal government playing different roles in the deployment of C/AVs, and 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, the federal government may step in and require all new automobiles to include such technologies. Such a scenario could lead to a rapidly increased market uptake, as has been the case when the federal government made such determinations in the past (Litman, 2017).

Chapin, et al. (2017) primarily consider the ways that cities would have to adapt their infrastructure to accommodate autonomous vehicles, and 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 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, which can often be compromised by catering to greater roadway capacity.

3.5 Summary

The astute reader may ask "But what about safety?" Indeed, for proponents of AVs, safer driving remains one of their most promising benefits. As mentioned earlier, the promise 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 (De Hartog et al., 2010). The confluence of factors from these four areas - 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.

Although not all of the literature we found brought pedestrians and cyclists into focus, all of the findings do have implications for how bicyclists and pedestrians interact with C/AV's. Research on C/AV crash avoidance generally relates to pedestrians and cyclists because of their notable vulnerability in automobile crashes. Research that examines changes to roadway infrastructure or the behavior of drivers may not explicitly concentrate on pedestrians and cyclists, but because cyclists and pedestrians share roadways with motorists – and are sometimes even motorists themselves – such research does have consequences for them.

In the course of conducting our literature review, we also discovered gaps in research on C/AVs, cyclists, and pedestrians. As discussed earlier, most experts anticipate a decades-long transition from a fleet composed mostly of level 0 vehicles, to one constituted mostly – but not entirely – by level 5 AVs. Despite this, much of the literature considers a world where *all* vehicles on the roadway are fully automated. This presents a gap in knowledge regarding the more immediate future of AV and pedestrian/cyclist interaction that deserves exploration.

4. Methods

This study uses semi-structured interviews of experts in academia, industry, and government to assess the state of knowledge and key issues for bicycle and pedestrian planning during C/AV deployment. Semi-structured interviews are a qualitative research method designed to explore topics (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 content and analysis of the interviews can help identify key issues and priorities for planning, policy, and future research. 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.

4.1 Questionnaire Design

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 Figure 2).

Figure 2. Interview Questions

General Connected/Automated Vehicles (C/AV) Future/Deployment

- Q1. Briefly, before focusing on pedestrians and bicyclists, what do you think is the time horizon for deployment and fleet saturation of C/AVs?

Impact of C/AVs on Built Environment, Urban Form, VMT, Safety

- Q2. How will C/AVs influence use of the right of way (streets, sidewalks), the built environment, urban form, and regional land use?

Impact on Pedestrians and Bicyclists

- Q3. 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?
- Q4. What challenges do you see for the interaction of C/AVs with pedestrians/bicyclists?
- Q5. What would you identify as key milestones in C/AV technology and deployment, as they relate to pedestrians and cyclists?

Solution

- Q6. What should be priorities for local, regional, state, federal law makers and planners guiding the transition to C/AVs as it relates to pedestrians/bicyclists?
- Q7. Who should pedestrian/bicycling planners work with in anticipation of the transition?
- Q8. When and how should pedestrian/bicycling planners start to get involved?

4.2 Identifying Interview Participants

First, our team of researchers identified a range of experts, balancing between academia, the public sector, and the private sector. Experts were also balanced between walking/biking experts and 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 (ANF10), bicycling (ANF20) 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 public and private sectors. During interviews, the research team also employed "snowball sampling,"[3] asking respondents to identify other potential respondents knowledgeable in the area of walking, cycling, and automated vehicles. Table 4 shows the information of interviewees', area of expertise, and sector types.

[3] Snowball sampling is a technique where interviewees are asked at the end of each interview to provide potential other interview contacts.

4.3 Conducting the Interviews

The researchers emailed interview invitations to candidate participants asking for participation in 40-45 minute phone interviews. Confirmed interviewees received a list of the semi-structured interview questions about two weeks prior to the actual interview. Institutional Review Board (IRB)-approved consent was obtained from each participant before the start of the actual interview. The project was classified as 'exempt' by Virginia Tech's IRB (FWA00000572; 18-064). Graduate assistants kept extensive notes during the interviews using a standard form to record all notes. The same interviewer conducted all interviews. At least one faculty member and at least one graduate student took notes during each interview. 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.

4.4 Data Coding and Analysis

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 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 text (e.g. one informant suggested….).

Table 4. 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	Private sector
4	Pedestrian/bicyclist expert, planning	Academia
5	Architecture and design	Academia
6	Chief Marketing Officer of an autonomous vehicle industry	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

5. Results

5.1 Factors Affecting Deployment of C/AVs

As part of the interview, respondents were asked their thoughts on the timeframe for deployment and fleet saturation of C/AVs. Their responses raised a number of considerations for planners, policymakers, and researchers. Answers touched on the transition process towards a more, and eventually fully, automated vehicle fleet, as well as major hurdles and milestones on the way to widespread adoption of C/AVs. Those considerations informed interview subjects' predictions on a deployment time-line. Some of the most prominent variables that interviewees mentioned as affecting the speed of the transition include the pace of technological development, business models and consumer preference, as well as regulatory/safety considerations.

5.1.1 Private Ownership or Shared Fleets?

A plurality of respondents foresees shared autonomous vehicles (SAVs) owned by firms and "hailed" by riders as the natural conclusion of C/AV technology. As such, a transition towards C/AVs is not just a matter of technological change, but also may represent a trend away from private vehicle ownership toward a model similar to how taxi and transportation network companies (TNC) operate today. Several respondents termed this trend, "mobility as a service." Most respondents who spoke on this point believe that SAVs will be the norm for AVs, at least at first – because AVs will be prohibitively expensive for most households, and because mobility companies can capitalize on their investment more easily than an individual household could. One respondent noted that the high cost for private owners and the durability of conventional automobiles would slow their replacement with privately owned C/AVs.

5.1.2 Context and Vehicle Type

Some respondents also hypothesized that we may see different types of C/AVs operate in different environments earlier than others. For example, one interviewee expects that within the next five years we will see CityMobil2-like projects in niche environments, for example, university and corporate campuses. Due to the more controlled environment of private roads and property, C/AVs will likely see widespread use on private campuses much sooner than on public roads. In these contexts, it is likely that private entities will use automated shuttles. One respondent expected that after C/AVs are used on private campuses and roads, they would be introduced to public roads with exclusive ROW before C/AVs are capable of universal, on-demand service. Some interviewees postulated that instead of confining C/AVs to specific lanes, some localities may only permit them to operate in geo-fenced areas where only C/AV, bicycle, and pedestrian travel are permitted. Ultimately, concerns over automobile safety may guide laws and regulations that determine how C/AVs are phased into the inventory of mobility options in cities.

5.1.3 Major Variables Affecting Deployment

As many interviewees noted, there are myriad variables that will determine the rate of market penetration. Technology, human behavior, market acceptance, demonstrated safety, policies, infrastructure, and price will all determine the pace of market penetration. Automobile manufacturers and technology companies still must overcome technological hurdles before the market experiences widespread adoption of C/AVs. Interviewees most frequently mentioned poor/insufficient detection and prediction of cyclists and pedestrians as the most prominent technological roadblock concerning the interaction of C/AVs and pedestrians and cyclists.

Technological and policy milestones may intertwine – regulatory bodies may set benchmarks for detection and prediction of pedestrians and cyclists or establish cyber security standards. Some respondents worried that many companies are turning a blind-eye to safety issues in a rush to establish market share. Interview subjects that believe that safety standards and regulations are needed also asserted that the C/AV technology must, at minimum, demonstrate that it is safer than human-driven automobiles.

Human factors will also play a role in a mode shift to C/AVs. One respondent noted that people – Americans especially – love to drive cars and will continue to do so even if C/AVs are available. Another took the opposite point of view and asserted that cultural norms around driving will be overcome by lower cost and greater convenience of C/AVs. A few noted that level-3 AVs may be a technological dead-end and most companies consider them too unsafe to develop due to driver hand-off issues. One respondent noted that there could be backlash against C/AVs – particularly automated busses – in the instance of a fatal vehicle crash.[4]

Lastly, the economics of C/AV use must make sense for companies and riders. Although the cost of AV technology has been dropping, it is still substantially higher than what most Americans spend on a traditional automobile. For this reason, a few respondents noted that SAVs will be the norm at first. Among others that spoke of widespread SAV-use, this seemed to be an implicit assumption. One respondent hypothesized that people would be willing to pay more to use C/AVs than traditional automobiles if they demonstrated substantial safety benefits.

5.1.4 Time

The previously mentioned factors all influenced interviewees' predictions the time-line of C/AV deployment and market saturation. Some respondents expressed uncertainty about a deployment timeline of C/AVs, either because of a lack of special knowledge or because they believe that there are far too many uncertain variables to consider. Some interviewees took automobile industry announcements at face-value and believe that highly-automated vehicles (HAVs) will be market-ready within the next 2-3 years. Although among those, some disagreement existed regarding the speed of adoption – one believed that fleet saturation would be achieved by 2022, while others believe that we are still decades away from most vehicle trips being taken by C/AVs. Of those that foresee a longer adoption period, they based their predictions off the average age of vehicles in the current fleet, the rate at which new automobiles technologies were adopted in the past, and the rate at which automobiles are replaced. Great variability existed among predictions, although few respondents believed that C/AVs would become the norm overnight, highlighting the diverse factors that will determine market uptake.

5.2 C/AVs, Right-of-Way, Built Environment, and Land Use

Many respondents believed that C/AVs will have varied effects on the built environment, urban form, regional land use, and right-of-way at multiple scales, including neighborhoods,

[4] It should be noted that the fatal crash that occurred with an automated Uber in Tempe, AZ (in spring 2018) occurred after most of our interviews had already been completed.

cities, metropolitan areas, states, and regions. Similar to current trends, some places will continue to pursue low-density, automobile-oriented development, whereas others will prioritize higher densities, mixed land uses, and non-automotive transport. Ultimately, local policies will determine right-of-way allocation, land-use policies, the built environment, and – to some extent – safety. If planners and policymakers give precedence to C/AVs, it could result in less investment in transit and active transportation.

5.2.1 Right-of-Way Allocation

Most respondents envisioned that widespread AV use will lead to changes in how the public right-of-way (ROW) is allocated. Exactly what changes occur will depend on vehicle ownership (private (PAV) or shared (SAV)) and the market penetration of C/AVs.

Many respondents assumed that SAVs will be more common than PAVs. They expressed a belief that a fleet of shared vehicles can transport more people with fewer automobiles. SAVs in particular can transport (other) people after their initial trip instead of being idly parked in a garage. One respondent noted that even when AVs park, they will require less space than traditional automobiles, because the doors do not need to open. Finally, many respondents expressed a belief that curbside space will be much more valuable for passenger pick-up and drop-off than for on-street parking in an SAV-dominant area. Together, these factors led many respondents to believe that cities will require less space devoted to parking than today, freeing both on- and off-street parking to be repurposed for other uses.

Respondents mentioned a number of ways that they believe vehicle operations will impact public ROW and vice versa. Some impacts may be different depending on whether a mixed or highly-automated vehicle fleet is operating in an area. It is worth noting that few respondents stated the exact same impacts, highlighting uncertainty about future developments. A few interviewees expressed a belief that travel lanes can be made narrower for C/AVs because they do not need to account for driver error or comfort. Further space savings could also be found by groups of HAVs platooning together allowing for increased vehicle throughput. However, both anticipated changes rest on the assumption that most or all vehicles on the roadway are highly automated.

With the newfound space that the interview respondents expect C/AVs to make available, two categories of use can be expected: driving and non-driving. As mentioned before, on-street parking could be repurposed as pick-up and drop-off zones, potentially bringing C/AVs into conflict with cyclists in unprotected bike lanes. Space created by narrower travel lanes could simply make room for more travel lanes. On the other hand, new space made available due to decreased lane width and on-street parking reductions could be devoted to non-automotive uses such as bike lanes and cycle tracks, pedestrian space, or dedicated transit travel lanes, or green space. While most respondents – especially those with backgrounds in academia and planning practice – envisioned the space being used for non-automotive purposes, one interviewee from the automotive technology industry expects that it will be used as additional capacity for C/AVs. These predictions all assume that mode separation as currently practiced will continue. However, a few interviewees responded that they believe modes should be further separated, while a few others anticipate that the safety advantages of C/AVs will allow for less separation of travel modes. Ultimately, the overarching message was that practice will vary from place to place and conform to local priorities, absent any state-level preemption of local planning efforts.

5.2.2 Built Environment and Sidewalks

If cities ultimately decide to cede curbside space to C/AVs for pick-up and drop-off it could lead to conflicts with cyclists and pedestrians on sidewalks and in bike lanes. Respondents noted that the conflicts will resemble those that cities grapple with today resulting from the proliferation of TNCs: automobiles crossing through or stopping in bike lanes and groups blocking pedestrian movement while exiting or waiting for a vehicle. A few respondents also expressed some concern that smaller C/AVs used for the delivery of goods will encroach on sidewalks and inconvenience pedestrians. A majority of respondents, however, either did not mention sidewalk "robots", had not considered their impact, or dismissed them as a novelty.

If SAVs become the norm, many interviewees expressed a belief that demand for off-street parking will plummet, though will not disappear entirely. In its place, they envision that greenspace and new development will fill in the spaces created by the reduction in parking demand. Another responded envisioned a hybrid model of development, where SAVs would become the primary automated mode of transport in dense urban cores where parking demand would decline, while PAVs would be the norm in lower density suburbs with plenty of parking.

Some respondents stressed that elements of the built environment represent expensive, durable, long-term investments on the part of public agencies and private firms. Additionally, as mentioned earlier in this report, most interview subjects believe that we are several decades away from the majority of new vehicles sold consisting of C/AVs. Considering these two factors, changes to the built environment that accommodate or account for C/AVs will likely take decades to proliferate.

5.2.3 Land-Use and Sprawl

Respondents noted that two diverging paths for urban development in a world with C/AVs exist: one that leads to increased sprawl and one with denser development. Due in part to the effects already mentioned – the possibility of more bike and pedestrian amenities and increased density from the repurposing of parking facilities – some interviewees think that C/AVs could result in less suburban sprawl. Conversely, some noted that because travelers will be able to devote their attention to pursuits other than driving, commute time will not have as high of a time-cost as today, and people may be more willing to take longer trips. If the more efficient use of roadways that some respondents envisioned materializes and is devoted to increased roadway capacity, it could induce travel demand as well. As one respondent stated, the policy instruments to control sprawl already exist, they only require the will of the public and policymakers to enact.

If C/AVs become commonplace, and especially if they are shared as most of the interviewees predicted, then the types and location of different land uses in cities may be affected. Many respondents postulated that land dedicated solely to parking could be developed or converted to park land. In one instance, a respondent said that they expect some underground parking structures to be converted to warehouse space for quick online deliveries. A few respondents also stated that land uses that cater to vehicle owners, like gas stations and auto-repair shops, will move out of major residential and commercial areas because they no longer need to be located within convenient distance from trip origins and destinations.

5.2.3 Safety

Related to the built environment discussed in the section above, a few respondents suggested that, due to potential conflicts between HAVs and other modes of transport, some localities may set up limited access zones—areas of cities with access restrictions for certain modes of transport. One respondent envisioned these as reserved exclusively for pedestrians, bicyclists, and perhaps transit. Another expects that they will exclude traditional automobiles and only permit HAVs, cyclists, and pedestrians on public ROW. Mirroring the other possible paths for development in a C/AV world, respondents suggested that any changes to land use will take a long time. One respondent stated that limiting pedestrian incursions into the ROW will be necessary to facilitate C/AV operations and safety, and pointed to the model of the Las Vegas strip as a place where automotive and pedestrian networks are completely separate.

Despite concerns over capabilities the current technologies in detecting pedestrians and cyclists and predicting their behavior, every respondent that talked about the overall impact on traffic safety believes that C/AVs will reduce the number of traffic collisions, injuries, and fatalities by eliminated human error and road rage. Although they expect overall traffic safety to improve, a couple of the interview subjects reported that they worry about conflicts that may arise between C/AVs and other modes of transportation, particularly on local and residential streets.

5.3 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. As with their answers to previous questions, answers to these questions were often qualified with a "it depends." Respondents agreed, however, that planning, policies, and standards may go a long way toward mitigating any potential negative effects for pedestrians and cyclists, but it remains uncertain as to how planners and policymakers will accommodate C/AVs.

5.3.1 Variability

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, upon being pressed, 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 impacts will vary temporally. In other words, 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.

5.3.2 Positive Effects

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 HAV behavior better than they can predict the behavior of human drivers. While many respondents had 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 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.

Individual respondents mentioned some other safety and health benefits of C/AVs for pedestrians and cyclists. One of those potential benefits includes the possibility to increase signal time for disabled pedestrians in a connected environment. Another is that environmental and noise pollution will be reduced if there is less stop and start traffic. Finally, another respondent stated that C/AVs will overcome some safety issues by travelling at very low speeds, as was done in the CityMobil2 project.

5.3.3 Negative Effects

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.

Towards the end of the series of interviews, the first pedestrian fatality from a HAV occurred when an Uber self-driving car struck and killed a pedestrian in Tempe, AZ. Some interviewees expressed concern that automobile manufacturers were willing to produce and sell cars with inadequate safety capabilities in an effort to establish early market dominance. 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.

In addition to safety concerns, interviewees expressed worry that bicyclist and pedestrian travel would be further constrained. This would partially be accomplished by increased mode separation, e.g. not permitting bikes to travel outside of bike lanes or making pedestrians wait longer at traffic signals. 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 not just by making active travel less convenient, but also 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 toward 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. A problem that could be made worse by inaccurate public perceptions of C/AVs' abilities. In the long-term, possible negative consequences of C/AV include further mode separation, increased constraints on bike and pedestrian travel, and negative public health outcomes if there is a mode shift away from active travel.

5.4 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; the technical capabilities of C/AVs; C/AV behavior and decision-making; communication; and infrastructure as a mediator or cause of conflicts.

5.4.1 Cyclist/Pedestrian Behavior and Expectation of C/AVs

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 that they highlighted is that pedestrians and cyclists behave unpredictably. If C/AVs become commonplace, easily identifiable, and prioritize cyclists and pedestrian safety, cyclists and pedestrians may alter their behavior on roadways. While this would contribute to the unpredictability of cyclists and pedestrians, it also could lead to another point of conflict. If they no longer have to worry about being hit, cyclists and pedestrians may use public ROW more assertively than today, slowing down 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.

5.4.2 C/AV Behavior and Decision-Making

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 feet 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.

5.4.3 Technical Capability of C/AVs and Detection

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 – is 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. 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.

5.4.4 Communication

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 and unpleasant 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. Another 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.

5.4.5 Infrastructure's Role in Mediating or Causing Conflicts

For the issues outlined above, infrastructure may mitigate or exacerbate conflicts. How cities plan for VRUs 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. In many ways, the same questions that planners face today regarding which mode infrastructure caters to and mode separation will continue to exist C/AVs.

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. It would be unsurprising to see some places trend more toward increased mode separation in attempt to ameliorate conflict, while others take a different approach and use the expected safety benefits to further integrate travel modes.

5.5 Milestones in C/AV Development for Pedestrians and Cyclists

5.5.1 Safety

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.

5.5.2 Policies and Regulation

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 DSRC (Dedicated short-range communication) will be antiquated by the time 5G wireless systems are 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; inadequate detection and prediction.

Interviewees also stressed the importance of testing. One respondent said a major milestone would be every state in the US allowing 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 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.

5.6 Priorities for Local, Regional, State, and Federal Law Makers and Planners

5.6.1 Technology/Auto Manufacturers

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. In the wake of the Tempe, AZ crash, another interviewee directly challenged this line of thinking. They said that immediately after the crash Uber and its suppliers all began pointing fingers at each other. 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 HAV crashes.

5.6.2 State and Federal Regulations

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.

5.6.3 Local Policies

As for local policies, interviewees did not provide many concrete examples of what should be done. A recurring theme among many answers was that localities should prioritize access 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 respondents 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.

5.7 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.

5.7.1 Tech, Mobility, Auto Industry/OEMs

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.

5.7.2 Public

Related to the previous point of not letting industry 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.

5.7.3 Elected Officials and Other Policymakers

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 bicycle 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 bicycle 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 bicycle and pedestrian travel constitute only a small part of how C/AVs may change our cities. But while this may be the case, most respondents saw the impact on cyclists and pedestrians as reason enough for planners to educate themselves and the public on the technology, and to work with industry and other public officials to ensure that the cyclist and pedestrian priorities are taken into account during a transition to C/AVs.

5.8 When and How Should Pedestrian and Bike Planners Get Involved?

Although many of the interviewees had touched on planning practices and policies that could be implemented to ameliorate any conflicts that C/AVs may be introduce, most had not discussed concrete steps that bike and pedestrian planners specifically could take. Near universal consensus existed among those interviewed that best time for bike and pedestrian planners to start getting involved in planning for C/AVs was at the present, if not the past. Some respondents expressed a lack of familiarity with what bike and pedestrian planners do. Nonetheless, most responses comported with answers to previous questions.

5.8.1 Education

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.

5.8.2 Changing Street Design and Infrastructure

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.

5.8.3 Repurposing Parking and ROW

Given that many of the interviewees foresaw demand reductions both in roadway capacity and parking supply, its 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.

5.8.4 Engagement with Policymakers, Automotive/Mobility/Tech Industries

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. As mentioned respondents also expressed 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 VRUs. 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.

6. Conclusions

6.1 C/AV Variability and Uncertainty

Evident from the variety of scenarios presented within and between answers by respondents, the future is uncertain when it comes to C/AVs and their effects on pedestrian and bicycle travel. There are a few different scenarios that may come to pass, although not all are mutually exclusive. We observed two major types of variability in respondents' answers to our questions, regarding (1) the speed of AV development and adoption, and (2) AV technologies, particularly the role of connectivity alongside automation.

First, the speed of AV development and adoption remains indeterminate and depends on many uncertain factors. Most respondents believe automotive industry announcements that HAVs will be available to consumers within the next five years, but predictions for market adoption vary widely. One respondent said that most trips will be taken in AVs within five years, while most interviewees expected that it will take at least a couple of decades before most new automobiles sold are C/AVs and even longer until the majority of all registered vehicles will be C/AVs.

Business and vehicle ownership models will influence the pace of adoption and how C/AVs will impact cities. The majority of respondents believe that initially SAVs will likely be the dominant form of automated transportation for economic reasons – private-ownership of a C/AV will be too expensive for most people and may not offer sufficient benefits to offset the additional cost over using a SAV. Because the cost and benefits of C/AVs are likely to determine which ownership model becomes more prevalent, it is possible that each of the two ownership models will be more common in different areas facing different costs and benefits. Today, transit, taxis, and TNCs are much more commonly used in more densely populated areas, while in suburban areas private vehicle ownership is the norm. That same arrangement may hold true for C/AVs as well.

If C/AVs come to replace human-driven automobiles, the transition is likely to take place over many decades. While most major automobile manufacturers expect to release HAVs by 2022, both the literature review and interviews show that – barring a new federal government requirement that all new vehicles be automated – a transition from a fleet of human-driven cars to one composed almost entirely of C/AVs will take several decades at minimum. This is important, because some of the most prominent effects on the built environment and ROW that interviewees mentioned, like narrower and fewer travel lanes, parking reductions, and replacement of curbside parking with dedicated pick-up and drop-off zones, are only realized if most vehicles on the roadway are automated. While respondents discussed how C/AVs may be adopted in phases – where they are deployed in some environments earlier than others – little attention was paid to how infrastructure and the built environment could cater to both C/AVs and traditional automobiles at the same time. The most commonly cited solution was for mode separation between automated and non-automated vehicles, either by creating C/AV-dedicated lanes or C/AV-only geographic areas.

In addition to the first-order effects mentioned above, some noted that mass changes in travel behavior due to C/AVs could result in different spatial development patterns, a second-order effect of C/AVs. If long-distance travel becomes more convenient because the cost of driving declines, then people may be more willing to travel further. Ultimately, this could lead to less dense metropolitan areas than what exists today. Conversely, if SAVs become the norm, and demand for on-site parking is reduced dramatically, parking facilities could be redeveloped for commercial or residential purposes, resulting in a potential increase in density.

While respondents noted that changes in the built environment and land-use would take a long time to accrue, none gave estimates or provided guidance as to when cities should or would begin making the changes that they anticipate. Similarly, many envisioned how a fully autonomous fleet would use roadway infrastructure, but only a handful discussed how a mixed-fleet would operate. It may be that the inclusion of C/AV technology on all new vehicles must be mandated before the widespread impacts of C/AVs on infrastructure design, the built environment, and land-use are fully realized.

Related to the idea of automation is connectivity. Some respondents suggested that V2V, V2I, and V2X communication will be essential for the safe and efficient movement of C/AVs, while others held the opinion that connectivity is altogether unnecessary. As with other scenarios, many of the variables that will determine the outcome are unknown at present. If C/AVs cannot operate safely without communicating with one another, with infrastructure, or with pedestrians and cyclists, connectedness may become the norm. The list of reasons why AVs may not be connected is long. If AVs are found to operate safely without communicating with infrastructure and other roadway users, it may not justify the investment in new, connected roadway infrastructure or in on-board technology. Some respondents expressed concern that connected AVs may constitute a public safety risk, if they can be hacked remotely. Lastly, some technological and non-technological developments may need to happen before C/AVs become feasible. For example, high-bandwidth, 5G wireless service may be necessary to communicate data quickly enough between entities. Standardized communication protocols between C/AVs, infrastructure, and other roadway users may need to be established before connected vehicles become feasible.

6.2 Key Challenges for C/AV, Bicycle, and Pedestrian Coexistence

Several key challenges for the coexistence of C/AVs, bicyclists, and pedestrians were identified through the literature review and interviews. Among them were: human and machine behavior, reliability of technology, human-machine communication, developing infrastructure that reduces or mitigates conflicts, managing a mixed-fleet, and questions around mode separation.

One of the most frequently mentioned points of conflict that interviewees said will likely emerge between C/AVs and pedestrians centers around changing pedestrian behavior. Many believe that if C/AVs prioritize pedestrian safety over quick and efficient vehicle movement – as every interviewee said they should – pedestrians could “take over the streets”, crossing whenever and wherever they please. By doing so they could discourage people from using C/AVs if they prove to be a less convenient form of travel than a traditional automobile.

Communication between C/AVs and pedestrians and cyclists could also present an issue. With human-driven automobiles, drivers and other roadway users may engage in non-verbal communication to indicate intent or to acknowledge another user on the roadway. Without a driver or development of an alternative means of communication, conflicts could arise between pedestrians and bicyclists and C/AVs due to a lack of two-way communication. Furthermore, most respondents noted that the detection systems that most current AVs are equipped with cannot fully detect cyclists and pedestrians, nor can they fully predict their behavior. Lastly, pedestrians and cyclists may not have a good understanding of C/AV capabilities. If they were to overestimate the vehicles' detection, prediction, or reaction capabilities, it could have fatal consequences. In a mixed-fleet situation, pedestrians and cyclists may also misidentify a traditional automobile as a C/AV, which could also pose safety risks.

While the aforementioned problems represent real safety risks in the near-term, both the literature and interviewees show substantial optimism for the potential of C/AVs to improve safety. The experts interviewed for this study identified a few potential solutions to account for those points of conflict. Most interviewees believe that the technological deficiencies will be resolved within the next few years. Some disparity was observed in how interviewees viewed pedestrians and cyclists "taking over" the street. Some viewed the integration of travel modes as a positive consequence of C/AV technology, while other saw it as a problem to be solved. The latter group proposed further separation, possibly by grade, and some of them suggested that barriers should be place between sidewalks and streets to prevent pedestrians from crossing wherever they please.

These challenges of technology, infrastructure, behavior along with the impacts on land use and the built environment can be addressed by planning and policy.

6.3 Role of Planning and Policy: Safety and Standards

The expectation of C/AV technology is that it will result in safer travel both for the vehicles' occupants and for other roadway users. But, as discussed above, 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 safety.

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 National Highways Traffic Safety Administration (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.

Based on the interviews, the role of states will change very little. They will continue to administer safety inspections of vehicles as they currently do, although they will have to formulate different requirements for C/AVs. 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 C/AV technology, local governments will be responsible for implementing infrastructure that fosters harmonious relationship between bikes and pedestrians. This could take many forms, and respondents stated that local priorities, which dictate development patterns, vary from locality to locality. Sidewalk, street, and intersection design may 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, with jurisdictions that value a diverse set of transportation options enacting different plans and policies from those that rely almost exclusively on single occupancy vehicles.

Few respondents mentioned public health implications of fewer people taking active transportation and riding in C/AVs more. Given that many are concerned that the cost and convenience of C/AVs could induce people to switch travel modes and the well-documented benefits of active travel, this appears to be a blind spot of current research.

6.4 Role of Local Planning and Policy: Local Ownership of Development Patterns

Because local priorities will determine policies, design, and development patterns, great variability will likely be seen between localities. 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 businesses 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.

Bicycle 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 interview 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.

Bike and pedestrian planners will also have input on infrastructure and land-use decisions in their jurisdictions. As mentioned earlier, a chief concern is how cyclists and pedestrians will interact with C/AVs on roadways. 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. On the other hand, planning and policy experts were optimistic 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.

Planners and engineers may also need to reconsider elements of street design to ensure that cyclists and pedestrians are not negatively impacted by C/AVs. At the moment, however, it is unclear precisely what they should change. One likely point of conflict that planners will have to confront is C/AVs – and to certain extent driver-operated TNCs today – crossing through bike lanes to drop off and pick up passengers at the curbside. Lastly, if the anticipated reductions in ROW dedicated to automobiles is realized, bike and pedestrian planners will have to advocate for this space to be rededicated for use by cyclists and pedestrians.

Finally, because one of the possible secondary effects of C/AVs is to induce travel, resulting in greater VMT, bike and pedestrian planners must work with comprehensive planners and land-use planners to prioritize denser development that is more conducive to active travel, and strengthen regional land use planning to prevent accelerated sprawl. While this is not directly related to bike and pedestrian infrastructure, it does impact their viability as a form of transportation. Because the health benefits of active travel are well-documented, it serves the public interest to implement planning practices and policies that encourage it, especially in the face of potential cost reductions in automotive travel brought about by C/AV technology.

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