Altarum Institute

Steering Autonomous Vehicle Policy: The Role of Public Health

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Executive Summary

The prospect of a coming boon in self-driving cars has captured the imagination of many Americans. Self-driving cars offer the promise of enjoyable, stress-free drives. In this report, Altarum Institute uses the terms “autonomous vehicle” and “AV” to refer to any vehicle that can drive itself some or all of the time without human intervention and without requiring the operator to continuously monitor the roadway.

From the perspective of public health professionals, AVs offer the potential to reduce automobile-related injuries and fatalities. They also offer the potential to provide access to reliable transportation for people who do not have it, reduce harmful automobile emissions, and, in the long term, even lead to land use changes that encourage walking and biking.

Cars that offer substantial or complete self-driving capability are expected to become available to the public by 2020 or shortly thereafter. Nobody can be certain, however, whether or, if so, when AVs will become the predominant mode of transportation.

What is certain is that the level of activity around AVs is already high. Nearly every major automobile manufacturer is investing in research and development of AVs, the U.S. Department of Transportation has indicated its intent to accelerate the adoption of AVs, four states and the District of Columbia have already passed legislation authorizing testing, and policymakers will soon be called upon to make a wide range of decisions that will affect the future of AVs, including their implications for public health.

This report aims to identify policy issues related to the use of AVs that will have a bearing on public health and to identify research topics that will support informed decisionmaking related to AVs and public health. To develop this report, Altarum interviewed a wide range of individuals, including public health professionals, industry representatives, researchers, and federal transportation officials. Altarum also conducted an extensive literature review.

Potential Public Health Benefits

Whether the significant benefits that could result from the widespread use of AVs will actually be realized will depend on the extent to which AVs become pervasive. Any benefits that accrue will likely increase over time as AVs make up an increasing share of vehicles on the road. The potential public health benefits are summarized below.

Traffic Safety

The first major impact of AVs will come in the form of reduced automobile-related injuries and fatalities. In 2014, more than 32,000 Americans died in motor vehicle crashes, and another 2.3 million people were injured. More than 90% of motor vehicle crashes are caused by human error. As AV technologies improve and the number of AVs increases, the quantity of motor vehicle crashes will almost surely decline.

Emissions

As AVs replace cars driven by people, automobile emissions are likely to decline, potentially resulting in decreases in pollution-related respiratory and cardiovascular disease. Reduced emissions, especially on a large scale, can also help mitigate the progression toward global climate change. Compared to current driving patterns, AVs will likely be able to drive more efficiently, with less stopping and starting and fewer accident-caused traffic jams. As AVs demonstrate their safe driving capabilities, they may even be able to shed some of the heavy safety equipment that adversely affects fuel efficiency.

Mobility

AVs offer the prospect of much greater mobility for those who cannot afford to own cars or cannot drive, including people who are blind, disabled, or simply past their safe driving years. Greater mobility can increase access to such things as work, health care, healthy foods, and the many necessities of daily life. Whether AVs will be transformational for these populations will depend on how the cost of accessing AVs compares to other transportation options, such as mass transit or emerging on-demand taxi services.

Physical Activity

Some researchers believe that AVs may lead cities to alter their land use practices to make cities more conducive to active transportation modes, such as walking and biking. This would result in higher levels of physical activity and its associated health benefits, such as a lower prevalence of people who are overweight or obese and at increased risk of a variety of health conditions. If AVs can simply drop off their operators and then park themselves at remote locations, space that is now used for parking could be repurposed. Furthermore, since less street parking would be required, streets and cities could become more compact and active transportation would become easier. Still, given the time and expense required to transform urban areas, any changes in land use resulting from widespread use of AVs would not come about for many years.

Potential Public Health Harms

Persons interviewed identified three potential adverse consequences that could result from the introduction of AVs.

Health Equity

Several public health professionals expressed concern that resources for public transportation, which is essential to people who lack access to other forms of reliable transportation, could be diverted to support the introduction of AVs. An increase in AV investments could result from the need for, for example, an upgraded traffic infrastructure to support AVs. Resources for public transportation could also be reduced as a result of perceptions that the success and popularity of AVs will lessen the need for public transit.

Increased Auto Emissions

Some believe that rather than reducing emissions, AVs will result in increased emissions. If people find AVs easy and convenient to use, total vehicle miles traveled will increase, more than offsetting pollution reductions that would result from more efficient driving. In addition, if AVs routinely drive themselves to retrieve passengers, that also may contribute to an increase in total vehicle miles traveled.

Reduced Physical Activity

While some believe that AVs could lead to increases in physical activity, others fear it might have exactly the opposite effect. With AVs, commutes might become so pleasurable and stress-free that people may be willing to commute from longer distances. This could lead to suburban sprawl, which typically discourages active transportation modes, such as walking and biking. Again, this result, should it occur, will undoubtedly be many years in the future.

Role of Government and Public Health

Strong economic and technological forces are moving the nation toward widespread use of AVs. Our initial review suggests that the public's health will benefit from this potentially transformational change in our transportation system, although the authors recognize that predicting long-term benefits and harms is fraught with uncertainty.

At the highest level, policymakers, with the input of the public health community, will need to address issues relating to overarching policy priorities and resource allocation. For example, in order to reduce automobile emissions and improve access to reliable transportation, how does investing in new transportation systems such as high-speed rail compare to making investments that encourage the use of AVs?

Policymakers will need to help ensure that decisions about AVs are made in the context of AVs' overall impact on society. For example, how should public reaction to AV failures that result in fatalities or injuries be weighed against the tens or hundreds of billions of dollars that could be saved each year by reducing traffic accidents?

Public health officials will also need to assume a leadership role in monitoring the impact on public health of the introduction and then widespread use of AVs. That includes determining the types of data that need to be collected and ensuring that needed data systems are in place.

Public Health Policy Issues

In the next several years, policymakers will be called upon to address important traffic safety issues. Examples include:

- **How can policy makers maximize safety during the transition from human-driven vehicles to AVs?** In the absence of certainty about how human drivers will react to sharing the roads with AVs, policymakers will need to determine how best to ensure a safe transition. One often-mentioned approach is to set aside designated roads or lanes for AVs so that they can operate without interference from human-driven cars and vice versa.

- **Should licensed drivers be required to be present and able to assume control of vehicles that are designed to be able to be in self-driving mode 100% of the time?** Policymakers will need to balance the benefits and harms of not requiring a licensed driver to be present and able to assume control of the vehicle. On one hand, most experts believe it is unrealistic to expect vehicles traveling in autonomous mode to never cause an accident. On the other hand, requiring a licensed driver to be present would limit AVs' ability to provide increased mobility to people who are unable to obtain a driver's license. It would also prevent fulfilling the vision of having AVs drop off their passengers and then either self-park at remote locations or drive to pick up new passengers.

- **What types of distracted driving laws should be in place for operators of vehicles that can operate in self-driving mode but require the operator to be available to assume control of the vehicle if needed?** Laws will need to specify whether or not any or all types of distractions are permissible before the vehicle hands off control to the driver. Closely tied to this are the issues of how best to notify drivers that they need to assume control of a vehicle and whether a minimum period should be specified for drivers to assume control.

In the longer term, the impact of AVs on such public health issues as automobile emissions, physical activity, mobility, and health equity will likely become increasingly important. Those concerned with public health need to be cognizant of the issues and be prepared to take a leadership role in developing policies that further public health goals. In some instances, planning decisions being made now about such things as transportation infrastructure, urban planning, and land use should consider the likelihood that AVs will be in widespread use in the future.

Research Priorities

In order to make informed policy decisions, policymakers will need information about a variety of issues related to the introduction of AVs. The federal government, with its overarching responsibility for public health, will need to allocate funding to assess the impact of AVs. The automobile industry will of course also continue to conduct research to ensure that AVs are safe and operate efficiently. Research efforts should focus first on those questions that need to be answered in the near term. Those are primarily traffic safety issues.

Research can later focus on public health benefits and harms that may occur in the longer term. Those areas include such things as the impact of AVs on automobile emissions and pollution-related disease, mobility for individuals who are transportation disadvantaged, mobility in rural areas, overall health equity, and the impact of land use changes on active transportation.

It should be acknowledged that there are many technological issues that are not discussed in this report that researchers will need to address in order to ensure that AVs can operate safely in real-life driving environments.

1.0 Introduction

Just as the invention of the gas-powered automobile transformed American life, another transformational change is on the horizon. The development of self-driving cars, often called autonomous vehicles (AVs), offers the potential to fundamentally change our transportation system and many aspects of daily life. One of the hoped-for benefits of self-driving cars is their potential to improve public health, primarily by reducing traffic-related fatalities and injuries, but in other ways as well.

Over the last several decades, much attention has been given to the relationship between transportation and health. For many reasons, national transportation policy is now recognized as an important part of national health policy. Traffic-related injuries and fatalities represent an enormous public health burden; automobile-related air pollution is a significant contributor to chronic disease, especially respiratory disease; greenhouse gas emissions from automobiles are the single largest contributor to global climate change; and land use policies meant to encourage automobile use and greater mobility can inadvertently discourage physical activity, including active transportation such as walking and biking.

The level of activity related to AVs is already frenetic. All across the automobile industry, manufacturers and suppliers are testing a plethora of AV technologies. As the technology advances, these vehicles are moving closer to becoming commercially available, with several automakers projecting that they will bring the first fully autonomous vehicles to market as early as 2020. In fact, many cars being sold today already make use of AV features, such as automatic braking, lane sensors, and adaptive cruise control.

The AVs that have captured the public's attention, however, are those that are fully self-driving, i.e., those that do not require any human control. Media reports about self-driving cars have stimulated interest in the topic. These self-driving vehicles give rise to images of people speeding along highways while they watch movies, surf the Internet, or perhaps even sleep.

Government officials, industry leaders, and many other interested groups will need to make many important, informed decisions if the nation is to fulfill the vision of roadways full of AVs. Several states have already passed legislation authorizing the testing of AVs, and other states are considering legislation.

Thus, the time is right for the public health community to begin to become active participants in developing policies that will affect the future of AVs. This paper is intended to raise awareness among public health professionals about the many issues related to the introduction of AVs that may affect public health.

2.0 Purpose and Methodology

At this early stage of development, nobody knows for sure what the long-term impact of AV technology will be on public health. Nevertheless, expectations are high that the overall impact will be positive. At the same time, given the potentially transformational impact of this new technology, the advent of AVs could have unintended consequences that harm public health. The time frame for this new technology to become widespread is uncertain, but it seems likely that the transition to AVs as a common, if not predominant, form of transportation—either fully autonomous vehicles or vehicles that have substantial self-driving capabilities—will begin in the coming years.

This report has two primary objectives: (1) to identify policy issues related to the use of AVs that will have a bearing on public health and (2) to identify research topics that will support informed decisionmaking related to AVs and public health.

The authors conducted interviews with a wide range of individuals, including public health professionals, industry representatives, researchers, and government officials. Information was also collected through an extensive literature review.

The paper is not intended to provide a technical review of the capabilities of AVs. Information about the technical capabilities and issues confronting AVs can be found in many places, such as in *Self-Driving Cars: The Next Revolution*, a report from KPMG and the Center for Automotive Research.[1]

3.0 The Future of AVs

3.1 What Are AVs?

The terms "autonomous vehicles" and "AVs" refer to a continuum of vehicles ranging from those that have few autonomous features to vehicles that are fully self-driving, requiring the "driver" only to provide destination information. AVs employ a variety of technologies to ensure they can make safe and intelligent driving decisions. The backbone of AV technology includes such features as the Global Positioning System, cameras and on-board sensors to view and understand the surrounding environment, and wireless technologies to communicate with other vehicles and/or with a sophisticated traffic infrastructure.

The National Highway Traffic Safety Administration (NHTSA) has developed a categorization framework to help develop a common language regarding AV functionality. NHTSA has defined five levels of AV vehicles, ranging from levels 0 to 4. The table below summarizes key differences between each level.

Exhibit 1: Levels of Vehicle Automation

	Level of Automation				
	Level 0	**Level 1**	**Level 2**	**Level 3**	**Level 4**
Primary responsibility for vehicle operation	Driver	Driver	Driver	Shared between driver and vehicle	Vehicle
Driver must constantly monitor roadway	Yes	Yes	Yes	No	No
Hands off steering wheel and feet off pedals at same time	Never	Never	In specific operating conditions	In specific operating conditions	Always
Transition from vehicle control to driver control	N/A	N/A	Driver to be available for control at all times and on short notice	Driver to be available for occasional control with sufficiently comfortable transition time	N/A

In Level 0 vehicles, the driver is in sole control of all critical vehicle functions, such as steering, throttling, and braking. At the other end of the continuum are level 4 vehicles, which are fully self-driving, requiring no driver control other than providing destination information. Level 3 vehicles allow for the vehicle to self-drive most of the time but also include a handoff function that requires the driver to occasionally take control as long as there is a "sufficiently comfortable" time for the transition.

In this report, the terms "autonomous vehicle" and "AV" refer to level 3 and 4 vehicles unless otherwise noted. These are the vehicles that offer the potential to transform American life. Level 3 and 4 vehicles allow people to ride in a car without having to give their attention to the road. Level 4 vehicles even have the potential to drive without any human occupants, enabling them to self-park or drive unoccupied to pick up passengers.

3.2 AVs and Daily Life

In a nation of drivers used to enduring stressful drives, the promise of self-driving cars is proving to be exciting. The prospect of spending time in the car more productively, enjoyably, and without the stress that comes with driving on traffic-filled streets has captured the public's imagination.

Imagine cars that deliver occupants to their destinations and then park themselves at remote locations, eliminating the need for parking-friendly cities. Without the need for street parking or large parking lots, streets could become narrower and cities could become more conducive to walking and biking.

Once the concentration of AVs is high enough, they should be able to reduce congestion as cars travel more smoothly and more closely together. In addition, fewer accidents would mean fewer accident-caused traffic jams.

The widespread availability of AVs may also change existing car usage patterns. Cars sit idly 90% of the time on average. Imagine if, after dropping off its passenger, the AV picked up another nearby passenger and remained in constant use as it shuttled riders around. Cars could be owned by multiple individuals. Alternatively, rideshare services could manage fleets of AVs while operating more economically than services requiring human drivers. In fact, young people are already waiting longer than their parents did to get their licenses and are commonly using transportation modes that do not require them to own cars.

Perhaps instead of flying from Los Angeles to San Francisco, the traveler chooses to make the drive overnight, sleeping all the way. Perhaps rather than coming home early from work, Mom or Dad orders an AV to pick up the kids and friends for soccer practice.

Another potential benefit is the opportunity to expand transportation options for persons who have limited access to reliable transportation. AVs open up opportunities for better access to work, health care, social interaction, and a host of other important activities.

The economic benefits of AVs could also be substantial. The greatest limitation in long-haul trucking, for example, is the number of hours for which an operator is permitted to drive before stopping. By not having to rely on human drivers, trucks could cut transit times in half.

It is easy to envision how AVs could enhance quality of life. Those responsible for managing the introduction of AVs into American society, however, will also need to be cognizant of any negative, unintended consequences that might result from widespread use of AVs. For example, will people find riding in AVs so easy and enjoyable that they walk and ride bikes less? As discussed later, an important role for policymakers will be to monitor the impact of introducing this transformational mode of transportation into daily life.

3.3 Will AVs Become Ubiquitous?

The potential public health benefits of AVs will be maximized only if AVs compose a significant proportion of the vehicles on the nation’s roadways. Improved traffic flow and reduced congestion, for example, will be difficult to achieve as long as conventional vehicles outnumber AVs.

Whether AVs will eventually become the predominant form of transportation in the United States will not be known for years. Nevertheless, NHTSA has stated, “Partially and fully automated vehicles are nearing the point at which widespread deployment is feasible.”[2] Nearly every major automobile manufacturer is investing in AV-related research and development, and at least several say they will have cars with fully self-driving capabilities available by 2020. Clearly, competitive forces and technological advances are driving automobile manufacturers to build vehicles with more and more autonomous features.

Even when all the technological challenges have been overcome, many obstacles could still interfere with the widespread adoption of AVs. Consumers will need to trust the new technology enough to be willing to turn the driving over to an AV. One fear of AV manufacturers is that unforeseen incidents may undermine public acceptance of AVs. Hacking events, for example, in which malicious attackers take control of AVs, perhaps resulting in accidents and injuries, could harm public confidence. For that matter, if unrealistic expectations lead the public to believe that AVs are accident proof, any AV-related accident could undermine consumer confidence.

Another obstacle that could slow or prevent widespread adoption of AVs is cost. The cost of this new technology will need to drop significantly in order for AVs to become affordable for most of the car-buying public.

Important legislative and legal issues will also need to be resolved before AV use can move ahead quickly. One potential obstacle is the possibility of state-by-state, patchwork legislation that imposes different requirements on AV manufacturers. Advocates for the development of AVs, especially industry representatives, have voiced concern that inconsistent and conflicting state laws will slow the development of AVs, requiring manufacturers to tailor their cars to meet state-specific requirements.

California is the only state thus far to address issues that go beyond testing to widespread use of AVs. In December 2015, the California Department of Motor Vehicles issued proposed regulations that would require individuals licensed to operate AVs to be in the vehicle while the AV is operating, even if the vehicle can operate in self-driving mode 100% of the time. Drivers would be required to be able to take control of the vehicles in the event of an autonomous technology failure or other emergency. The regulations are not final and will be the subject of public comment in 2016. Still, the regulations have provoked strong opposition from the AV industry, which contends that the regulations will stifle innovation, especially by limiting the development of AVs that do not allow for drivers to take control of the cars.

Finally, liability issues will also need to be resolved before AVs can be sold widely. Who will be liable when self-driving cars are involved in accidents—the manufacturer or the operator?

Assuming that AVs become widely available in the next decade, it will still be a number of years before they become predominant on the roads. Typically, 6%–7% of the automobile fleet consists of new vehicles,[3] so a minimum of 7–8 years would be required after AVs become commercially available before they could make up half of all cars on the road. Realistically, it will be even longer than that, since AVs will be sold alongside non-AVs for a number of years before AVs dominate new vehicle sales. Some of the reasons mentioned above, such as affordability, may extend the period of transitioning to AVs even further. Also, there will undoubtedly be many people who will simply prefer to continue driving cars in which they can control all aspects of the vehicle's operation.

Nevertheless, it seems inevitable that AV use will grow over time. Only the rate of adoption is uncertain.

4.0 The Impact of AVs on Public Health

Transportation and health are interconnected in many ways. At the most basic level, transportation enables access to important activities fundamental to daily life (e.g., work, education, health care, shopping, recreation). Beyond that, though, many health issues are closely linked to transportation: traffic safety, health risks due to pollution, stress, and the impact of land use policies on physical activity. The introduction of AVs may affect each of these issues in significant ways. This section explores those connections.

4.1 Traffic Safety

The most obvious and most significant public health benefit resulting from the widespread use of AVs is likely to come in the form of reduced traffic fatalities and injuries. In 2014, more than 32,000 Americans died in motor vehicle crashes, and another 2.3 million people were injured.[4] Researchers estimate that human error contributes to 94% of all motor vehicle crashes.[5] According to NHTSA,

- Alcohol-related crashes account for about one-third of fatalities,
- Ten percent of fatalities are caused by distracted driving,
- Drowsy driving accounts for nearly 3% of crash fatalities, and
- Nearly half of those killed are not wearing seatbelts.

In addition, the financial toll associated with motor vehicle accidents is enormous, estimated in 2010 to total $242 billion. The costs include, among other things, medical costs, lost productivity, congestion costs, and property damage.[6]

AVs may even be able to prevent some accidents that are not caused by human error. Those include accidents caused by roadway defects (e.g., large potholes) and accidents caused by pedestrians, bicyclists, or other vehicles.[7]

The biggest challenge that AV developers face is enabling AV vehicles to recognize and react to the wide variety of road conditions and driving situations that drivers encounter. Early testing by Google has demonstrated the potential of AVs to reduce traffic accidents and traffic-related injuries. As of March 2016, Google's AVs had driven more than 1 million miles in self-driving mode and caused only one accident.

The introduction of AVs will require policymakers to address a number of issues that will bear directly on traffic safety. Important issues include testing of AVs, how best to ensure safety when AVs and conventional vehicles are sharing the road, distracted driving laws, tailgating laws, and assorted other roadway issues discussed below.

4.1.1 Testing

Nearly every major automobile manufacturer is currently testing AVs, yet the testing process itself presents significant challenges. Meaningful testing needs to take place in actual driving settings, but that means testing in settings where any safety failures can be serious.

In 2013, NHTSA offered nonbinding recommendations to states concerning testing of AVs. NHTSA recommends, among other things, that states

- Require that there be a properly licensed driver in the driver's seat ready to take control of the vehicle if needed;
- Limit testing operations to roadway, traffic, and environmental conditions suitable for the capabilities of the vehicles being tested (e.g., limiting testing to certain locations, certain types of roads, or certain speeds);
- Ensure that the process for transitioning from self-driving mode to driver control is safe, simple, and timely;
- Ensure that AVs can detect, record, and inform the driver of system malfunctions; and
- Establish reporting requirements to monitor the performance of the AV technology, including in crashes and near crashes.

In 2016, NHTSA signaled that it would more aggressively support efforts to advance AV use and would be flexible in allowing automakers to test new technologies. It encouraged automobile manufacturers to request that it use its exemption authority to approve testing of AV fleets.

California, Florida, Nevada, Michigan, and the District of Columbia have passed legislation explicitly authorizing AV testing. It is unclear whether state legislation is actually required for companies to test AVs, but legislation does serve the purpose of establishing at least some parameters for testing.

4.1.2 Transitioning from Human-Driven Vehicles to Autonomous Vehicles

Some researchers have suggested that traffic safety risks may actually increase during the transition period in which AVs and conventional vehicles share the road.[8] Certainly any transition period is likely to exist for many years as drivers decide whether to buy AVs and as conventional vehicles continue to occupy the roads until retirement.

The way in which human drivers will react to sharing the road with self-driving cars is not known. Human drivers may have expectations about the behavior of AVs that could create unsafe traffic conditions; e.g., drivers may believe that they can always force AVs to yield the right of way. Also, the consequences of human drivers not being able to use some forms of human communication that contribute to safe driving, such as making eye contact with each other, are far from clear.

One strategy that has been suggested to smooth the transition from conventional vehicles to AVs is to create designated roads or lanes for AVs only. This would limit interactions between AVs and conventional vehicles and would likely help maximize the benefits of AVs, such as smoother traffic flow and improved fuel efficiency.

Questions for policymakers include whether to build new lanes for AVs (requiring new budget outlays) or make use of existing lanes. While using existing roadway space would be a less expensive way to build designated lanes, it would result in fewer lanes for non-AVs, perhaps increasing congestion, fuel usage, travel time, and even safety risks for non-AV drivers. Research is needed to understand the public health implications of the various options and the implications for AVs and conventional vehicles alike.

4.1.3 Requiring Licensed Drivers in Self-Driving Vehicles

An important issue for states is whether to require level 4 vehicles to allow for human drivers to take control of the vehicle. Policy guidance issued by NHTSA in 2013 recommends that states require "a properly licensed driver (i.e., one licensed to drive self-driving vehicles) be seated in the driver's seat and be available at all times in order to operate the vehicle in situations in which the automated technology is not able to safely control the vehicle."[9] This is similar to the proposed regulations in California.

This requirement would have the effect of prohibiting the use of AVs that have no provision for enabling human drivers to assume control. It would limit the ability of people who are currently unable to obtain licenses (e.g., some persons with disabilities, some seniors) to take advantage of the capabilities that AVs offer. Policymakers will need to determine what level of assurance that AVs can operate safely is needed before they allow AVs to operate without a licensed driver present.

4.1.4 Amending Traffic Safety Laws

The introduction of AVs will require policymakers to consider whether to amend current traffic safety laws, such as distracted driving and tailgating laws. One of the most appealing features of AVs is that human operators can spend their time in the car on tasks other than driving—working, reading, browsing the Internet, watching movies, doing crossword puzzles, and even sleeping. As discussed, however, level 3 vehicles will require humans to take control of the vehicle at certain times.

Thus, an important challenge facing policymakers will be whether to adjust distracted driver laws, especially in AVs that use level 3 automation, to cover operators of vehicles while the vehicle is in self-driving mode. Presumably, distracted driving laws governing driver behavior while a vehicle is in person-driven mode will continue to apply. Currently, every state has laws restricting drinking and driving. In addition, 46 states prohibit texting by drivers, and 14 states prohibit handheld cellphone use by drivers.[10]

Complicating the issue is that people have different levels of anxiety and clear thinking in stressful situations (i.e., when required to take control of a vehicle). They also may face different types of distractions at the moment they are expected to assume control of the vehicle. For example, some may be watching a movie, while others may be sleeping. Policymakers and researchers will need to consider such issues as what types of activities are permitted or prohibited while "driving" level 3 cars and what types of alerts should be required for drivers to reengage when necessary. Research suggests that nonvisual cues, such as auditory and haptic cues, work best.[11]

Tailgating laws are just one more example of how state traffic safety laws may need to be updated. Tailgating laws are intended to keep a driver at a safe distance behind the car in front. AVs will likely be able to follow other cars more closely than human-driven cars, thus making more efficient use of roadway space. AVs will be able to react almost instantaneously to other vehicles' changes in speed and direction, certainly more quickly than drivers' hand and foot responses.[12] Again, policymakers will need to balance the advantages of more efficient traffic flow against the potential increased safety risk of allowing cars to travel more closely together.

4.2 Emissions

AV technology offers the potential for a cleaner environment, less pollution-related disease, and fewer greenhouse gas emissions. High levels of pollution can trigger or exacerbate respiratory diseases such as asthma and chronic obstructive pulmonary disease. Pollution even increases the risk of heart disease and heart attacks.

Furthermore, greenhouse gas emissions are a significant contributor to atmospheric changes and global climate change. Climate change, with all its associated consequences, can potentially increase the incidence of allergies, asthma, diarrheal disease, and heat-related deaths.

Several aspects of AV technology may serve to reduce air pollution and greenhouse gas emissions. Once enough AVs are in use, traffic flow will likely be smoother, largely as a result of there being fewer accidents to disrupt traffic. An automobile fleet with AV technology will be able to drive more efficiently, especially with AVs that can communicate with each other and inform each other when they are changing speeds or stopping and starting. AVs can also eliminate the "emotion" that humans often bring to driving (e.g., wanting to speed past other cars). Advanced navigation systems on AVs will help drivers find the most efficient travel routes.

In addition, as accidents decline, legislators and regulators may allow cars to become lighter by not requiring them to carry heavy safety equipment, thus enabling AVs to use fuel even more efficiently. Finally, AVs are more likely than human-driven cars to rely on electric power, partly because electric systems can better help power the array of technology that AVs will utilize. Cars will likely be able to improve their miles-per-gallon performance and, for electric cars, be able to go farther on a single charge.

Whether these benefits would be partially or fully offset by increases in vehicle miles traveled is not yet known. If people find AVs easy and convenient, they may choose to "drive" when they otherwise may not have traveled at all or may have used some other form of transportation. If a shared AV ownership model becomes common, or if AVs are called upon as taxi services, the added miles resulting from AVs driving to pick up passengers may also contribute to an increase in total vehicle miles traveled.

4.3 Land Use, Urban Design, and Physical Activity

There are conflicting opinions on whether widespread use of level 4 AVs will lead to significant changes in land use and, if so, whether those changes will encourage or discourage the use of health-promoting active transportation modes, such as walking and biking. The hopeful view is that AVs will be able to drop off their riders and then park themselves at remote locations. As a result, parking lots and spaces, which currently consume about one-third of the land area of some U.S. cities,[13] may be able to be used for other purposes.[14] Likewise, if vehicle sharing overtakes private ownership, cars will be on the road for longer periods and parked less of the time, thereby reducing the need for parking capacity. Furthermore, streets could become narrower if street parking becomes less necessary, and fewer lanes would be needed if cars could drive closer together. Under this optimistic vision, widespread use of level 4 vehicles could lead to redesigning cities so that they are more compact, meaning that they would be more conducive to active transportation.

The less optimistic view is that AV use may lead to suburban sprawl. If riding in an AV becomes more enjoyable, less stressful, and more productive, suburban living will become more appealing. As a result, people will be willing to commute from longer distances. Houses, businesses, and schools are typically spread out in suburbs, making them less conductive to active transportation.

Public health professionals will need to monitor the actual implementation of AV technology closely to assess the potential impact on land use and, ultimately, physical activity. Whatever the changes, they are not likely to happen for many years, given the time and expense needed to significantly change land use and the urban landscape.

4.4 Stress

A potential benefit of AV technology, albeit one that is difficult to quantify, may be reduced stress. Stress is a risk factor for serious illness, most notably cardiovascular disease.[15] Once AVs are prevalent, drivers will likely encounter smoother traffic flow and fewer accident-caused traffic jams. They will also know with a fair amount of precision when they will arrive at their destination. Rather than becoming stressed over slow commutes to work and other places, drivers may be able to enjoy their rides and even be productive while in the car.

Even here, though, there are conflicting views. Some contend that AVs may actually add to driver stress. Drivers may feel the need to monitor the external environment as well as the operation of the vehicle's self-driving features, making driving even more stressful.[16] Again, future research will be needed to determine impact on stress.

4.5 Mobility and Health Equity

The issues of mobility and health equity are very much intertwined. Health equity has been defined as "the absence of systematic disparities in health (or in the major social determinants of health) between groups with different levels of underlying social advantage/disadvantage…"[17] Access to reliable transportation is an important element of health equity, although health equity goes well beyond transportation.

Researchers have shown that access to reliable transportation has a significant impact on health.[18,19] Among other things, access to good transportation improves economic opportunities and outcomes, which are directly related to good health. Nearly 15 million people in the United States, however, have difficulty getting the transportation they need.[20] Lack of access to good transportation can adversely affect physical, mental, and emotional health. It can limit access to health care, work, shopping, healthy foods, recreation, and social interaction.

4.5.1 Health Equity

Hopes are high that the many positive benefits that result from the widespread use of AVs will help to improve health equity. Low-income families typically devote a substantially higher proportion of their income to transportation. In addition, they often live where housing is more affordable (i.e., outside city centers) and where access to public transportation is limited.

An often-discussed benefit of AVs is their potential to change the traditional model of private car ownership. Shared ownership or shared use of AVs (e.g., widespread use of on-demand taxi services but with self-driving cars) could be cheaper than having to buy an AV for one's own use. Research will be needed to compare per-trip costs with an AV to other transportation modes.

Furthermore, government agencies charged with delivering services to those populations where health inequities are highest may be able to take advantage of AVs. They may be able to develop programs that provide improved transportation options to facilitate access to health care, healthy foods, and more.

At the same time, policymakers need to be cognizant of AVs' potential negative unintended impacts on health equity. Access to AVs may be limited if the price of AVs makes them unaffordable to many, especially if a shared-use market fails to develop as hoped.

Several people interviewed expressed concern that AVs may even exacerbate health inequities by diverting resources from transportation investments that benefit those who have limited access to good transportation. The success and popularity of AVs could result in perceptions that less investment in public transit is needed. Resources could also be diverted if communities choose to invest resources in upgrading their traffic infrastructure to communicate with AVs (i.e., in a "smart streets" architecture).

Furthermore, the introduction of AVs could lead to reduced government revenues, which could result in less spending on mass transit or other needed services. Reduced revenues could result from less demand for parking, fewer traffic infractions, less public transit use, and even lower gas tax revenues if AVs drive more efficiently.

4.5.2 Mobility for Low-Income, Older, and Disabled Individuals

Those who are transportation disadvantaged stand to benefit the most from the introduction of level 4 vehicles. Included in this group are people who cannot afford to buy a car and people who cannot drive. That includes many seniors, many people with disabilities, blind people, and children.

Laws or regulations that require a licensed driver to be present in a level 4 vehicle, such as the draft regulations issued in California, would be a barrier to increasing mobility for those who cannot drive and who might otherwise benefit from self-driving cars. Governing authorities will need to weigh traffic safety risks against the desire to give those who are transportation disadvantaged better opportunities to be mobile.

Older Americans may benefit significantly from the availability of level 4 vehicles. For many seniors, the inability to drive creates social and economic problems. More than 20% of Americans age 65 and older do not drive, because they do not have a car, are concerned about safety, or have poor health or eyesight.[21] Many other seniors are at risk because they continue to drive beyond their safe driving years.

Likewise, AVs have the potential to significantly improve transportation options for persons with disabilities. Six million people with disabilities have difficulty getting the transportation they need.[22] Current paratransit systems are expensive to operate and often do not serve the needs of their customers efficiently, turning routine trips into long and difficult ordeals.[23] A fleet of AVs that could be deployed more efficiently offers the potential to improve this system.

Whether AVs will be transformational for people without access to reliable transportation will likely depend on how the cost of accessing AVs compares to other transportation options, such as mass transit or emerging on-demand taxi services. This is an issue that policymakers and researchers will need to monitor closely.

4.5.3 Mobility for Rural Populations

The impact of AVs could be especially significant in rural areas. Safety benefits could be substantial, since motor vehicle crashes occur at disproportionately high rates in rural areas. This is due to the correlation between per capita vehicle miles traveled and crashes.

For people without cars in rural areas, transportation challenges can be immense. The cost of operating bus and rail systems in rural areas is often prohibitive because of low population density and long travel distances. In many rural counties, public transit is nonexistent, often leading to both physical and social isolation.

For rural populations, AVs offer the prospect of lower cost travel and greater public health benefit due to their increased flexibility. Shared vehicle models, in which cars can self-drive from one rider to another, can lower car ownership costs and/or per-trip costs. Rural counties may also be able to find ways to use AVs for tailored “mass” transit without having to invest in fixed route buses or rail systems, such as by purchasing self-driving buses or passenger vans that pick up people wherever they are.

5.0 Discussion

5.1 The Role of Public Health

Public health has a long history of advocating for advances in traffic safety. Public health professionals played an important role in enacting mandatory seatbelt laws. Likewise, public health agencies strongly supported mandatory air bags. These laws were especially important when media reports of air bag-related injuries could have slowed or reversed progress in making air bags required safety equipment.

Likewise, as AVs begin to become a part of the nation's transportation system, public health professionals will have an important role to play in determining how best to reap the public health benefits of widespread AV use while minimizing potential harms. While there will undoubtedly be obstacles along the path to implementing widespread adoption of AVs—some that can be anticipated, others that cannot—the authors believe that strong technological, economic, and social forces will continue to move the country in that direction.

As discussed, societal public health benefits include reduced traffic-related injuries and fatalities, less pollution-related disease, reduced congestion and stress, a positive impact on climate change, and increased mobility for people who do not drive or do not have easy access to reliable transportation.

The near-term challenge for public health professionals is how to react to potentially transformational but still uncertain change. Government should not stifle innovation, but it should also provide leadership if trends move in directions that conflict with societal interests, including any adverse effects on public health.

Public health professionals have several important roles to play as AVs begin to come into widespread use. At the highest level, policymakers, with the input of the public health community, will need to address issues relating to overarching policy priorities and resource allocation. For example, what is the net benefit of investing billions of dollars in transportation systems such as high-speed rail in order to reduce automobile emissions, reduce motor vehicle accidents, and improve accessibility if the use of AVs will help achieve those same goals? Would delaying decisions about these kinds of large investments be wise until we know more about the impact of AVs? Data-driven analyses by public health agencies and researchers can help inform these decisions.

Similarly, public health officials can bring a rational and objective voice to deliberations on the future of AVs. For example, the advent of AVs offers the potential to significantly reduce the more than $240 billion in spending resulting from automobile accidents each year. Those savings alone could far exceed what the nation spends on public health, on improving health equity, or on reducing auto emissions. A wise use of data and risk communication strategies can help ensure that decisions about AVs are made in the context of AVs' overall impact on society. This may be especially important in the face of, for example, public reaction to AV failures that result in fatalities or injuries.

A core function of public health is assessment, as articulated by the Institute of Medicine.[24] The assessment function includes identifying data and/or developing data systems to assess the impact of emerging trends that affect the public's health. Clearly, the potential widespread use of AVs warrants organized, formal attention from government, which will need to monitor the impacts, both positive and negative.

The public health community, with its expertise in epidemiology, data analysis, and underlying determinants of health, is well-situated to assume leadership in monitoring these impacts. Public health can lead in determining the types of information that need to be collected and assessed and can help ensure that appropriate data systems are in place.

Thus, an important role for public health is to develop indicators to monitor the impact of AVs on public health. The Centers for Disease Control and Prevention and the Department of Transportation have already collaborated to develop a transportation and health tool to help decisionmakers understand how transportation decisions affect health. (See https://www.transportation.gov/transportation-health-tool.) A similar, perhaps expanded tool can provide a framework to assess the public health impact of AVs.

Examples of the types of information that an assessment tool would provide follow:

- **Traffic safety**—overall traffic safety data comparing crashes, injuries, and fatalities in AVs versus non-AVs, number of AV-caused accidents while in self-driving mode, information on the handoff from self-driving to manual mode, and information on those affected by crashes (e.g., whether a rider in the AV, a rider in another vehicle, a pedestrian, or a bicyclist);

- **Environment**—fuel efficiency and emissions information and impact on pollution-related diseases;

- **Health equity**—affordability and accessibility of AVs to low-income populations, as well as changes in access to the necessities of daily life (e.g., work, health care);

- **Mobility**—accessibility to AVs for those who cannot afford to own cars, accessibility to AVs of those who cannot drive, use of AVs by government agencies to improve access to needed services, and impact in rural communities; and

- **Land use and urban design**—a longer-term measure that would measure impact on physical activity, active transportation, walkability of cities, and suburban expansion.

Ultimately, input from a variety of stakeholders should determine which measures are most important to monitor. This will help create a strong foundation of support for monitoring public health impact. The stakeholders should include state and federal agencies responsible for traffic safety, environmental protection, disease surveillance, and health promotion; industry representatives; and transportation and public health researchers.

5.2 Policy Issues

The previous section identified the larger challenges that policymakers will face, such as making informed resource allocation decisions and the need to ensure that rational policymaking prevails in the face of short-term pressures. This section addresses several concrete policy issues that policymakers will need to address in order to help ensure that AVs can realize their potential safety and other benefits. The authors have identified what they believe are the most pressing and potentially the most contentious safety issues that public health officials and other policymakers will need to consider before level 3 and 4 vehicles become commercially available. Longer-term issues are also identified.

Policymakers will initially need to address at least three critical safety issues that will bear directly on whether AVs are adopted for widespread use:

- **How can policymakers maximize safety during the transition from human-driven to self-driving vehicles?** Nobody knows with certainty how human drivers will react to sharing the roads with AVs. Policymakers will need to determine how best to maximize safety and minimize disruption during the transition from conventional vehicles to AVs. One often-discussed approach is to set aside designated roads or lanes for AVs, at least on certain roadways. This would allow AVs to operate without interference from human-driven cars and would ease potential uncertainty among human drivers. Research is needed to assess the impact, on AVs as well as non-AVs, of establishing designated roads or lanes.

- **Should licensed drivers be required to be present in level 4 vehicles?** The California Department of Motor Vehicles has issued draft regulations that require licensed drivers to be present and ready to take control of the vehicle at any time. Clearly, legislators and regulators do not yet have 100% confidence in the safety of level 4 vehicles. The requirement, however, limits the ability of AVs to fulfill the vision of providing increased mobility to people who are unable to obtain driver’s licenses, such as some disabled individuals, some seniors, and blind people. The requirement would also prevent level 4 vehicles from self-parking at remote locations or dropping off passengers and then self-driving to pick up new passengers. Policymakers will need to decide what level of assurance they need of AVs’ safety capabilities or what level of risk is acceptable in order to allow level 4 vehicles to operate without licensed drivers present. Public health professionals should be actively involved in discussions about risk tolerance.

- **What types of distracted driving laws should be in place for operators of level 3 vehicles while the vehicle is in self-driving mode?** In level 3 vehicles, the AV will occasionally need to notify the driver that the driver needs to assume control. Laws will need to specify whether any or all types of distractions are acceptable (e.g., should sleeping be allowed?) before handing off control to the driver. Closely tied to this are whether standards should be developed for how to hand off control to drivers and whether a minimum period should be specified for the driver to assume control.

It should be noted that many other technological issues directly affect safety but are beyond the scope of this paper. Those include, for example, cybersecurity issues to prevent hacking, requirements concerning the types of communication technologies and capacity that AVs must possess, and federal policies regarding bandwidth available to AVs to communicate with other vehicles or with a technologically advanced traffic infrastructure.

While traffic safety will be the first public health issues that policymakers will need to address, many longer-term issues will arise. In order to improve mobility for those who are transportation disadvantaged or cannot afford to buy AVs, governments will want to explore strategies to encourage vehicle sharing and to utilize AVs to enable access to needed services. There will be issues related to emissions; for example, what policies can help ensure that AVs optimize fuel efficiency? In rural areas, governments may look for ways to make use of AVs as a cost-effective means to meet local transportation needs.

In the long run, widespread use of AVs may enable policymakers to encourage active transportation through changes in land use and urban design. Urban design and land use discussions taking place now should consider that AVs are likely to be commonplace in the future.

5.3 Future Research

Much information is needed to enable those responsible for ensuring the public's welfare to make informed decisions. Transformational changes of the magnitude that could result from AVs warrant the federal government investing in research on the impact of AVs. The automobile industry will also need to continue to assume its traditional research responsibilities to ensure automobile safety and efficient vehicle operation.

This report has identified a number of areas where new research will be needed. A research agenda examining the impact of AVs on public health should be structured to focus first on questions that need to be answered to support decisions in the near term. Those questions relate most importantly to the impact of AVs on traffic safety. Research can then focus later on questions that will support decisions in the longer term.

Researchers will need to address several overarching questions:

- How can the traffic safety benefits of AVs be maximized, including on occupants of AVs as well as on occupants of other vehicles, bicyclists, and pedestrians?

- What policies can best ensure traffic safety during the transition period from manually driven vehicles to fully self-driving vehicles?

- What will the impact of AVs be on automobile emissions and, ultimately, on pollution-related disease?

- To what extent will AVs assist with mobility for those who do not have easy access to reliable transportation?
- How can mobility be improved, including in rural areas, by re-allocating investments in fixed route transportation systems to more flexible systems?
- How can those who are at highest risk for poor health benefit from the advent of AVs?
- What impact will AVs have on land use, urban design, and health-promoting active transportation?

As mentioned in the previous section, many technological issues that require further research related to the safe operation of AVs are not discussed in this report. In addition, while the focus here has been on direct public health impact, it is worth noting that other impacts that are less directly related to public health could be far-reaching.

To the extent to which the transportation system becomes more efficient and people can use their time in cars more productively, AVs will likely provide significant economic benefit. Certainly the impact on the automobile industry will be substantial. If vehicle sharing becomes common, the number of vehicles sold will likely decline. The long-term impact on automobile dealer distribution networks and supply chains could also be significant. In addition, the introduction of AVs is likely to harm some sectors, such as automobile insurers, automobile body shops, and drivers of commercial vehicles.

The authors encourage schools of public health and public health researchers to assume a leadership role in understanding how AVs will affect the public's health.

6.0 Conclusion

The high level of private-sector activity and investment in AVs, combined with public fascination about these futuristic cars, suggests that AVs will eventually become common on the nation's roadways. The authors believe that on the whole, the potential public health benefits of AVs outweigh the likely harms, and the benefits will likely grow as AVs make up an increasing portion of the nation's fleet of automobiles. At the same time, however, the authors recognize that many unknowns surround the introduction of AVs and how they will ultimately be incorporated into daily life. Thus, predicting their long-term impact on public health is fraught with uncertainty.

To date, AVs have received little attention from the public health community at large. Often, the press of day-to-day public health challenges makes it difficult for public health officials to adequately consider the impact of future societal changes that may affect public health. In the case of AVs, however, the fact that the impact could be profound and that policymakers and major companies are already beginning to make important decisions underscores the need for public health professionals to begin to devote attention to the issue and to become active participants in policy discussions.

Given the potentially transformational impact that self-driving cars may have on daily life, public health leaders have important roles to play. As stewards of the public's health, public health leaders need to insert themselves into discussions and deliberations about the advent of AVs. The goals of establishing healthy communities and healthy environments need to be front and center as AVs become common on the nation's roadways. The nation will be well-served if public health is proactive in shaping state and national policies concerning AVs rather than watching from the sidelines as important decisions are made.

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