MOBILITY PLAN 2045

Appendix K

Connected and Autonomous Vehicles

K. CONNECTED AND AUTONOMOUS VEHICLES

INTRODUCTION

Fully autonomous vehicles that are capable of operating independently of a driver will one day become a reality on our roadways. What remains unclear, at least at this point, is the timeline for when these vehicles will be able to do this, when they will make up the majority of traffic, the degree to which the driver is no longer responsible for safe operation, and how the implementation of such vehicles will be conducted. Most experts, including the Society of Automotive Engineers (SAE), believe that connected and autonomous vehicles (CAVs) will be integrated in a phased approach based on the degree of automation and connectivity that exists in the vehicle fleet as well as the supportive capacity of roadway infrastructure and communication systems.

Given the novelty of autonomous technology at this point, most experts and transportation professionals (such as the SAE, the U.S. Department of Transportation, and others) recommend a phased approach when planning for the implementation of autonomous vehicles. This type of approach not only make sense from a practical standpoint but would also help to reduce sharp impacts to industries, allowing for greater time to adjust to new operating environments and technological developments. In this context, implementation is taken to mean both the increased use of autonomous vehicles by all consumers of the transportation network, as well as proliferation of connected and autonomous vehicles (CAVs) in policy discussion and public thought.

A key distinction exists between levels of automation and phases of automation. Levels of automation throughout this document are based off the SAE International's automation levels (further discussed in Section III) and refers primarily to the degree to which automation exists within each vehicle. Phases of automation considers the automation level of the majority of newer cars being produced and is a less definitive measure of both the degree of automation in most cars at that time and the proportion of traffic operating with limited or full automation at that time. Phases of automation have no clearly defined beginning and end, and rather represent a slow progression leading to each phase with considerable overlap. The phases of automation are further discussed and defined in Section IV of this document.

PUBLIC VS. PRIVATE RESPONSIBILITIES

A significant concern for CAV development and adoption, as with any emerging technology, is what responsibility public agencies, such as local governments, should take throughout the development, accommodation, and proliferation of Connected and Autonomous Vehicles. Private industry will likely remain a key driver in CAV adoption, creating and sustaining the demand that would eventually lead to proliferation of CAVs. Because of this, public-private partnerships, not only for financing, but also to maintain awareness of technological progress, are vital to successful and seamless integration of CAVs onto our roadways.

As will be discussed in depth further, infrastructure upgrades and maintenance are a key component of ensuring our roadways are ready and able to support CAVs at all phases of development. It is unlikely that infrastructure projects and maintenance will move beyond the public realm. Given the high costs associated with infrastructure upgrades, it is critical that public agencies across the region remain aware and continue to monitor technological requirements identified during CAV development. This will allow for greater flexibility and a more accurate ability to forecast future needs and identify potential issues.

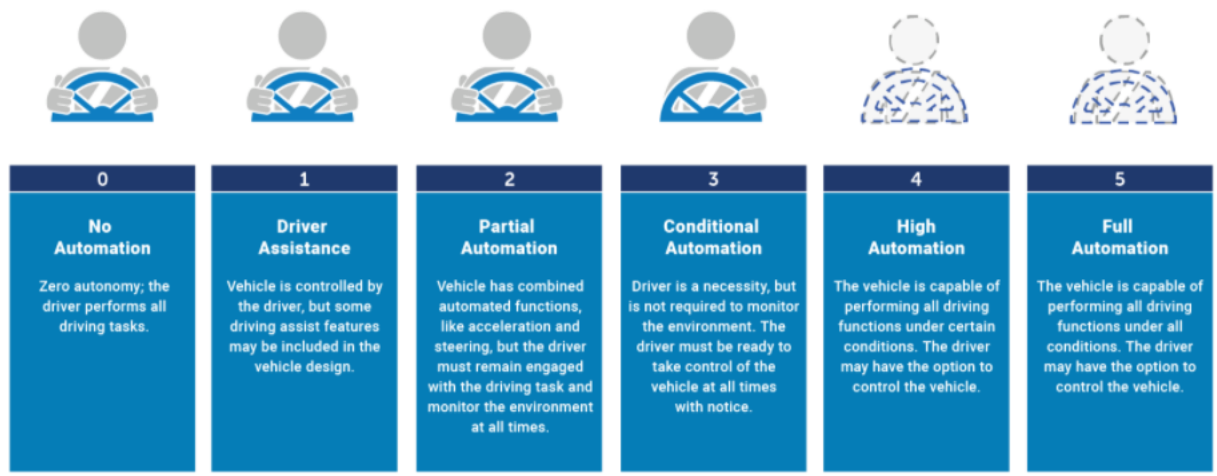
Maintenance will also be a central issue in the discussion of public vs. private responsibilities. Current CAV technology relies heavily on cameras to sense the environment and guide the vehicles. Therefore, things such as roadway markings and pavement conditions take on greater importance as technology functions best under predictable circumstances, possibly leading to a higher level of maintenance required for roadways once CAVs begin to operate independently. Data management, networks, and connectivity are also critical components for CAVs to operate efficiently and safely, leading to potential questions of whether such things will begin to be considered part of highway infrastructure, and thus within the public realm. CAVs themselves will also require a higher degree of maintenance than current automobiles, bringing questions of what role public agencies will play in ensuring proper maintenance of CAVs for their safe operation on the road, as well as potential liabilities should a crash occur when a vehicle is operating completely autonomously.

State and local governments have a primary interest in making sure people can get where they need to go safely. Local governments within the TPO area will likely remain the primary agents for enforcing traffic laws, conducting safety inspections, planning, and operating transit and roadway infrastructure.

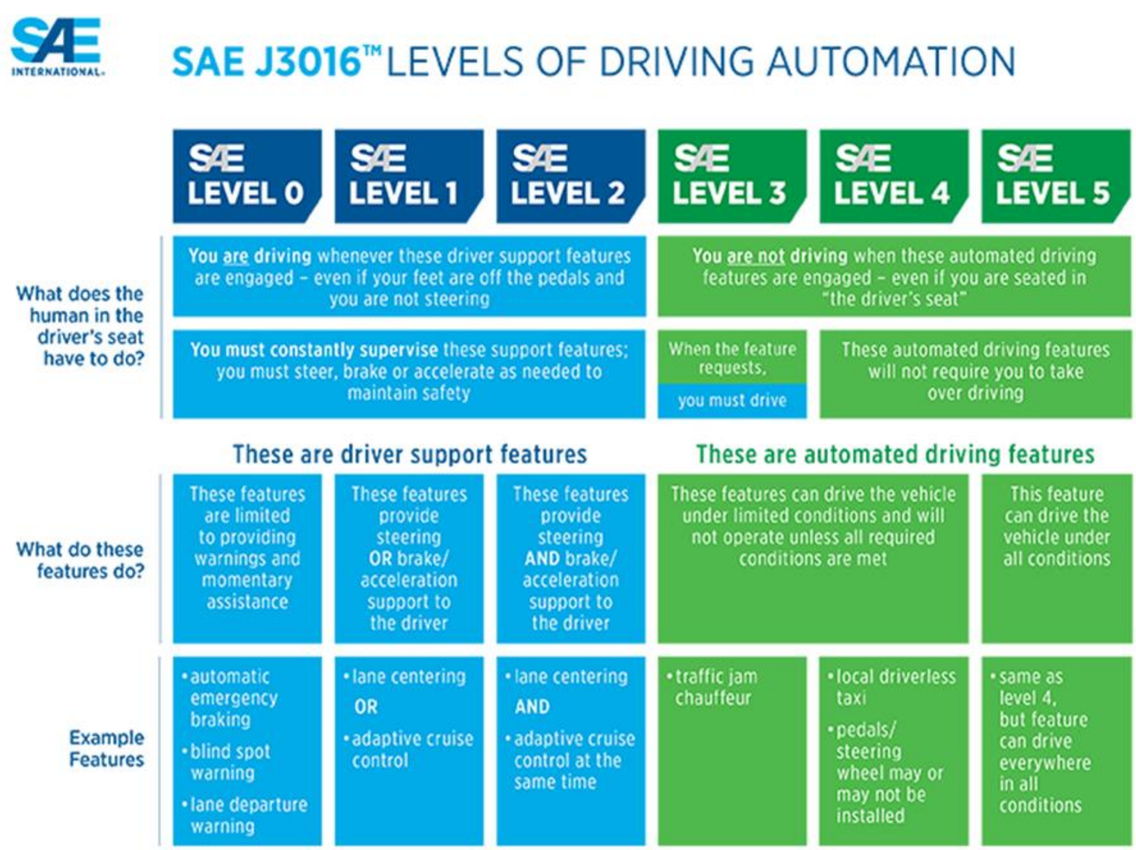
Additionally, the U.S. DOT recommends that state and local governments prepare for automated vehicles through the following measures (U.S. Department of Transportation, 2018):

- Review laws and regulations that might create barriers to testing and deploying automated vehicles.
- Adapt policies and procedures to account for automated vehicles.
- Assess infrastructure elements, such as road markings and signage, so that they are conducive to the operation of automated vehicles.
- Provide guidance, information, and training to prepare the transportation workforce and general public.
- Stay abreast of technological developments as autonomous technology progresses.
- Understand the near-term opportunities that automation may provide.
- Consider how land use, including curb space, will be affected.
- Facilitate safe testing and operation of automated vehicles on local streets.
- Engage with citizens throughout the CAV implementation process

LEVELS OF AUTOMATION



Source: Automated Vehicles for Safety: The Road to Full Automation, 2020. National Highway Traffic Safety Administration.

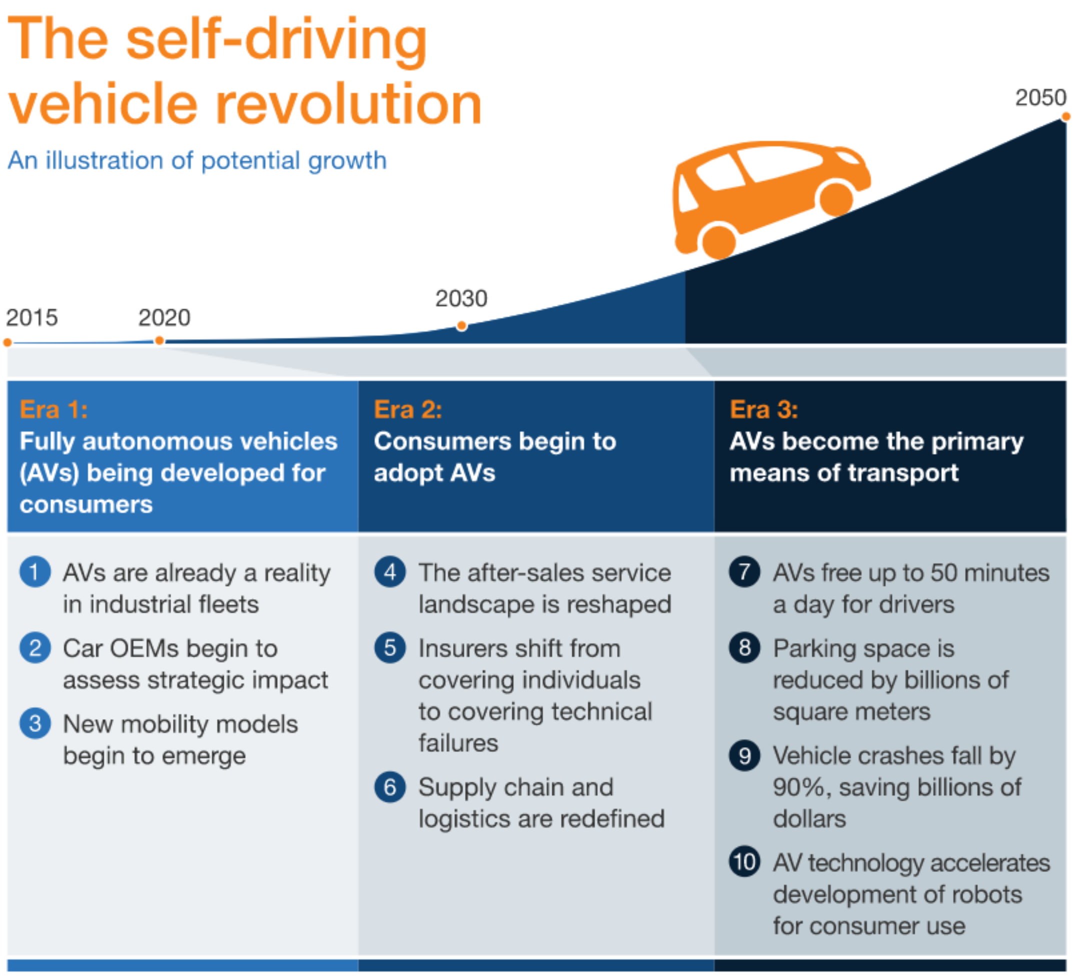


Source: Jennifer Shuttleworth, 2019, SAE International Administration

- Level 0 – No automation. Driver provides the dynamic driving task, although there may be systems in place to help the driver (i.e. emergency braking).
- Level 1 – Driver assistance. Lowest level of automation. Vehicle features an automated system for driver assistance (steering assistance and adaptive cruise control). Driver still monitors other aspects of driving such as steering and braking.
- Level 2 – Partial automation. The vehicle can control both steering and acceleration. Driver still monitors safe operation and can take control of the car at any time.
- Level 3 – Conditional automation. Vehicle has "environmental detection" capabilities and can make informed decisions autonomously. Still requires human override and the driver must remain alert and ready to take control if the system is unable to execute the task.
- Level 4 – High automation. Vehicle can intervene if things go wrong or there is a system failure. Human drivers not required in most circumstances, but a human still has the option to manually override. *Level 4 autonomous vehicles will likely be geofenced and only able to operate fully autonomous in certain areas or under certain circumstances until enough machine learning is acquired to pass safety measures to enter full automation.
- Level 5 – Full automation. Vehicles do not require human attention and the dynamic driving task is eliminated. Level 5 vehicles also do not need steering wheels or acceleration/brake pedals. *Level 5 autonomous vehicles would be able to operate anywhere and with mixed traffic.

PHASES OF CAV ADOPTION

As with any emerging technology, the proliferation of CAVs onto our roadways will take a phased approach, both due to technological limitations, as well as the market forces that drive such change. The determining factor for each phase will likely be the level of automation available in most newer vehicles operating on the roadway at the time. Such an approach will likely take many decades to transition between each phase, with no clear or neat separation between each phase, but instead a gradual shift between them. The illustration below shows this concept and demonstrates how market forces affect both the development and adoption of CAVs.



Source: Ten ways autonomous driving could redefine the automotive world by Michele Bertoncello and Dominik Wee, 2015. McKinsey & Company.

Phase 1: Combined Function Automation

Characteristics

The first phase of CAV adoption is characterized by most newer privately owned vehicles being equipped with levels 0-2 of SAE automation. The driver is still responsible for safe operation of the vehicle, and must take an active role in all tasks related to driving. Features such as adaptive cruise control, lane assistance, parking assist, and other Advanced Driver Assistance Systems (ADAS) may fulfill some driving tasks such as acceleration and steering, but overall, the driver must actively monitor and take a primary role in all driving functions for safe operation of the vehicle.

Development

Most experts agree that we are currently in phase 1 of CAV adoption as CAV technology is being rapidly developed and tested across the country. During this phase, private demand and market forces will likely continue to lead to increased levels of ADAS which will slowly develop into more automation and less direct involvement from the driver during vehicle operation. Supply chains and private corporations will also likely become early fielders of CAV technology as this phase progresses due to the financial benefits of innovation and early adoption of CAV technology.

Regional Impacts and Implications

During this exploratory phase, agencies across the region should continue to monitor CAV technological progress in order to better forecast future needs and demands. Policy discussion during this phase will likely center around future implications of further CAV development and adoption, as well as regulatory issues that might arise as CAV technology progresses and vehicles are able to operate more autonomously in later phases.

Phase 2: Limited Self-Driving Automation

Characteristics

The second phase of CAV adoption and integration will be characterized by newer vehicles reaching SAE levels 3 and 4 of automation. These vehicles will be able to operate autonomously under certain conditions and in certain situations. The driver is still required and must be ready to take control of the vehicle at any time, but does not need to be consistently and actively engaged at all times and in all driving functions. Features such as “traffic jam chauffer” are available and can operate autonomously when certain conditions are met in predictable scenarios.

Development

This phase will again be largely driven by private adoption of new CAV technology with ever increasing capacity for automation. During this phase, significant “machine learning” will likely begin as vehicles begin to operate fully autonomously under specific conditions. Private companies will likely also begin to significantly adopt CAVs to operate certain functions, such as on-campus shuttles, “last-mile” delivery and truck platooning to reduce costs and expand services offered.

Regional Impacts and Implications

During this phase, the regulatory novelty of CAV technology will likely become a significant factor in policy change and discussion (both locally and nationally). Agencies will likely be required to take a more active role in regulating CAVs and CAV adoption, especially in areas such as responsibility and vehicle maintenance to ensure safe operation and make determinations of liability when collisions occur. This phase would likely also see increased demand for highway maintenance and public/private partnerships to pay for necessary infrastructure upgrades to facilitate further CAV adoption.

Phase 3: Full Automation with Mixed Traffic

Characteristics

This phase is characterized by most newer vehicles coming with SAE level 5 automation, where the vehicle is capable of performing all driving functions under all conditions. During this phase, the driver of a fully autonomous vehicle will no longer be required to play an active, or even passive role in driving or monitoring the vehicle’s operation. While the driver may have the option to control the vehicle, some fully autonomous vehicles in this phase will likely begin to lack common features of cars such as steering wheels, pedals, mirrors, etc. This phase, however, is differentiated from the final phase of CAV integration because these fully autonomous vehicles will be operating alongside vehicles with lower levels of automation, and even some with no automation.

Development

While this phase is characterized by privately owned vehicles operating autonomously across a wide range of locations and scenarios, commercial enterprises, such as freight, delivery services, and mass transit will also likely be early adopters of fully autonomous vehicles due to the financial benefits. In fact, because of these cost benefits, corporations and even some public agencies will likely be among the first to develop and field fully autonomous vehicles in this phase.

Regional Impacts and Implications

Because fully autonomous vehicles will have to operate along with non-autonomous vehicles, there exists greater safety concerns in this phase. Machine learning may have issues attempting to predict human behavior that might run counter to the logically best choice at the time. Responsibility and liability concerns will likely remain a major issue during this phase. For example, the insurance industry may be completely restructured to cover maintenance costs rather than collision liability as crashes become less frequent and maintenance standards are increased for CAVs. Our region, in particular, would likely see significant changes during this beginning of widespread CAV adoption due to the many insurance and freight companies located within the area. Regulatory and policing practices would also begin to change significantly, as less time would be devoted to traffic stops and crash investigations. Significant infrastructure upgrades will also be required during this phase in order to accommodate the increased usage of CAVs across roads within the region.

Phase 4: Full-Automation with Near Total Automation

Characteristics

This phase of CAV integration is characterized by the proliferation of SAE level 5 autonomous vehicles. In this phase CAVs make up all, or nearly all, commercial and private vehicles operating on the roadway. With SAE level 5 autonomous vehicles, the driver is no longer required to monitor driving functions, and instead the machine maintains complete responsibility for all driving functions across all scenarios. Because of this, liability issues will remain a major topic of discussion with regards to who is responsible for both incidents, as well as maintenance of the vehicle. During this phase, private ownership of CAVs might cease, and instead individuals would lease vehicles directly from manufacturers or third parties.

Development

Unlike the previous phases where corporations or public sector agencies drive development and proliferation, during this phase private consumers will likely create the market forces that result in full proliferation of CAVs. This phase will likely take the longest due to this, but will likely also see the most significant shift to industries affected by CAV proliferation (such as insurance companies, local law enforcement agencies, rest stops, travel services, etc.).

Regional Impacts and Implications

During this phase, safety concerns shift away from potential collisions and driver neglect and more towards system level safety for the entire transportation network. Issues such as cyber security, maintenance concerns, and environmental impacts become the main public safety concerns for transportation due to the physical safety dividends paid by widespread CAV integration. During this phase, the transportation network becomes increasingly accessible to vulnerable populations, such as the elderly and persons with disabilities, allowing for significant positive economic impacts as these groups are able to live more independently.

During this phase CAVs free as much as 50 min/day/person freeing up travel time for productive activities, with potentially 1 billion hours of time saved per day globally. CAVs could also reduce need for parking space in the US by more than 5.7 billion square meters, as parking spaces can be made 15% tighter due to no need for people to exit. For example, in Knoxville, there are approximately 21 parking garages or public parking lots in and around downtown. With approximately 300 square feet for each parking space, simple math would indicate that the redevelopment of these spaces for more productive enterprises could yield significant economic benefits for our area. (Bertoncello, 2015) (Kavanagh, 2015).

By midcentury, the penetration of AVs and other ADAS could ultimately cause vehicle crashes in the United States to fall from second to ninth place in terms of their lethality ranking among accident types. Today, car crashes have an enormous impact on the US economy. For every person killed in a motor-vehicle accident, 8 are hospitalized, and 100 are treated and released from emergency rooms. The overall annual cost of roadway crashes to the US economy was $212 billion in 2012. Taking that year as an example, advanced ADAS and AVs reducing accidents by up to 90 percent would have potentially saved about $190 billion. (Bertoncello, 2015).

POTENTIAL ISSUES SURROUNDING AUTOMATED VEHICLE TECHNOLOGY

Connected and Autonomous Vehicles (CAVs) present a host of potential issues that must be taken into consideration at all phases of development and integration. Issues and negative impacts associated with CAV integration primarily center around safety concerns during the initial development and integration phases, as well as significant costs associated with infrastructure upgrades needed to fully integrate CAVs into the transportation network.

Safety

Safety challenges are most significant during the initial phases of CAV integration. While this point may seem fairly obvious, practical experiences are needed to generate and enhance machine learning. As CAVs encounter new challenges or issues from use, updates to software can be generated to better predict and learn from these experiences. Additionally, safety challenges will likely reach their peak during Phase III of CAV integration when CAVs will be operating in mixed traffic with human drivers. Issues would likely arise from the machine's inability to predict likely actions taken by human drivers that may be at odds with the optimal actions programmed into CAVs. These initial safety concerns will most likely reduce significantly once full automation occurs in Phase IV due to the high-level of machine learning and predictability of machine behavior during this phase, however cyber security issues will likely remain present throughout the entirety of CAV integration.

Cost Burden

Another significant concern associated with CAV adoption and integration are the high costs of the infrastructure upgrades needed to fully integrate CAVs. CAVs would require a constant stream of information in order to operate safely and effectively. This would likely come from sensors, transmitters, and other electronic components located along roadways, such as on signs, traffic signals, and on road striping. Additionally, once infrastructure upgrades are complete, maintenance standards and costs would be much higher than today due to the price of such electronic components, as well as the need to maintain road markings to remain visible to cameras and sensors on CAVs. CAVs may also present an equity issue, as costs associated with private ownership and maintenance would likely be high, especially during the initial phases of adoption and integration.

Budget Shortfalls

The majority, if not all, CAVs would likely be electric vehicles, due to convenience factors associated with electric motors and the large proportion of electric components needed to effectively operate autonomously. Because of this, CAVs could deepen the revenue shortfalls associated with gas taxes, leaving significant funding shortfalls in federal and state budgets for roadways as CAV integration progresses. Governments at all levels will be tasked to identify new revenue streams to maintain the transportation infrastructure.

Policy

Since CAVs are an emerging technology, there exists a significant amount of uncertainty in the planning process. Because of these unknowns, there remains a host of administrative and policy related challenges around CAV integration. Issues will likely remain for the foreseeable future surrounding liability and responsibility, not only for safe operation, but in instances of malfunction as well. For example, insurance companies will likely have to significantly restructure policies due to CAV adoption. If a fully autonomous vehicle is involved in a traffic collision, who is responsible for the damages?

Regulatory

There is also a degree of uncertainty for regulatory agencies and governing bodies' responsibilities in the implementation of CAVs. For example, should public funds be used for required infrastructure upgrades needed to implement a private company's fleet of autonomous vehicles, or should partnered funding be used? Legislative bodies and regulatory agencies will also likely have to restructure existing policies and mechanisms to effectively regulate a transportation network dominated by CAVs. Municipalities in the region would likely have to retrain and restructure law enforcement and parking enforcement once fully autonomous vehicles make up the majority of traffic. Local governments in the area will also have to adjust their structure and practices as transportation needs may greatly shift, moving away from major infrastructure involvement to more of a regulatory capacity. Another potential shift that widespread CAV use might cause would be a shift in security focus away from internal security (such as safety measures, speed monitoring, DUI enforcement, etc.) to a focus on protecting from external threats to the transportation network (such as cybersecurity, terrorism, weather, and environmental impacts). This would essentially result in a refocusing away from local level issues (i.e. driver safety, local traffic patterns, etc.) to more system level issues that might be outside of the scope of local governments within the region.

POTENTIAL BENEFITS OF CONNECTED AND AUTONOMOUS VEHICLE TECHNOLOGY

While there potentially are, and likely will remain, issues with CAV adoption and integration, the probable benefits to the region and transportation network are numerous and substantial. The National Highway Traffic Safety Administration (NHTSA) has highlighted four main areas of potential benefit regarding CAVs: Economic and societal, efficiency and convenience, mobility, and safety.

Economic and Societal

The widespread adoption and integration of CAVs can provide a host of potential economic benefits for the region. A 2010 NHTSA study showed that motor vehicle crashes in that year cost $242 billion in economic activity, including $57.6 billion in lost workplace productivity, and $594 billion due to loss of life and decreased quality of life from injuries. During the final phases of CAV integration, parking garages, plazas, and on-street parking real estate located in city centers and other high-density areas will be available for redesignation and development, allowing new businesses and attractions to be brought in. In certain situations smaller roadways required for CAVs could also potentially reduce right-of-way requirements in high density areas and city centers, allowing for reallocation of previous motorized space to non-motorized modes. Additionally, improvements in pedestrian safety will greatly improve the walkability of urban areas, stimulating economic growth and improving public health. Local budgets within the region might also see a significant shift in public safety priorities. Funding traditionally allocated to things such as DUI enforcement, combating speeding and distracted driving, and might instead be used to fund other activities and free up law enforcement within the region to focus on other aspects of public safety. (National Highway Traffic Safety Administration, 2020).

CAV adoption could also have significant benefits for equity and access to the transportation network. Widespread CAV adoption could potentially lead to a shift away from private ownership of vehicles, leading to increased use of ride-share systems, autonomous taxis, or even leasing/renting vehicles directly from manufacturers. Shifts in consumer demands such as these have the potential to considerably decrease the costs of accessing the transportation network. This would be especially impactful for an area such as Knoxville with a large proportion of senior citizens, low-income communities, persons with disabilities, and other vulnerable populations. CAVs also have the potential to greatly reduce costs and increase levels of service for public transit, allowing for even greater access to transportation through public transit providers and an extension of services to larger areas within the surrounding community. Greater equity resulting from widespread CAV proliferation could also pay considerable economic dividends as vulnerable populations within the region would be afforded greater independence and the ability to more fully participate in the local and regional economy through employment and consumption of goods.

Environmental

With most vehicles transitioning to electric motors during the CAV integration process, negative environmental impacts to the region would significantly be reduced. This would lead to improvements in air and water quality with a reduction in vehicle emissions and storm water contamination from parking lot and roadway runoff. Noise pollution and impacts to wildlife habitats would also be reduced due to less idling and engine noise. Deer strikes and other collisions with animals would likely be greatly reduced once CAVs make up the majority of traffic on the roadway as a result of improved decision making and reaction time.

Efficiency and Convenience

CAVs will likely provide greatly increased efficiency in the transportation network, freeing up commuting times to more productive activity. A 2015 study estimates that approximately 6.9 billion hours were spent in traffic delays in 2014, and also estimates that CAVs could free up as much as 50 minutes per person per day on average. Widespread CAV implementation in freight could also provide economic benefits by reducing supply chain needs and costs, allowing for greater purchasing power by consumers, and subsequently leading to increased demand for goods amongst consumers. The reduction in unproductive commuting times and reduced aversion by consumers to longer commutes will also lead to a larger labor pool for our area as more remote areas become increasingly connected to regional hubs, such as Knoxville. Conversely, there also exists a potential increase in sprawl as residents might relocate further away from regional hubs, such as Knoxville. (Bertoncello, 2015).

Mobility

It remains to be seen when, how, and to what extent CAVs will be implemented throughout the region, resulting in difficulties in projecting societal benefits from CAV implementation. There exists, however, substantial potential benefits in both increased mobility and increased accessibility to transportation by vulnerable populations such as the elderly, disabled persons, and those living below the poverty line. Currently, there are 49 million Americans over the age of 65, and an additional 53 million Americans with some form of disability. According to a 2017 study conducted by the Ruderman Foundation, CAVs could create new employment opportunities for approximately 2 million people with disabilities through providing new mobility options. Across much of the country, employment and independent living rests on the ability to drive. (Claypool, 2017).

Safety

Perhaps the most significant and impactful benefit from full CAV integration would be the major improvements in roadway safety across all modes of transportation. Vehicular collisions would be greatly reduced and possibly eliminated during the latter phases of CAV integration by eliminating human error and unpredictability. These safety benefits would also extend to pedestrian, freight, bike, and other modes of transportation, allowing for increased volumes of multi-modal transportation. (National Highway Traffic Safety Administration, 2020).

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