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Adaptation of Autonomous Vehicles into Highways and Roads

Kasim Korkmaz, Ph.D
Eastern Michigan University
Ypsilanti, MI

Hyun Jeong Koo, Ph.D.
Wayne State University
Detroit, MI

Autonomous vehicles (AVs) are considered as the one of main components of the future transportation system. By 2040, over 90% of the vehicles are expected to be autonomous vehicles in the U.S. Therefore, it is imperative that the infrastructure systems, including highways and roads, need to be updated accommodate AVs before they become prominent in the transportation system. The main benefits of AVs are easing congestion, shortening commutes, reducing fuel consumption and global warming, enhancing accessibility, the liberation of parking spaces for better uses, and improving public health and social equity. To provide the current state of adaptation of AVs into highways and roads, the objectives of this paper are to investigate the current legislation and to explore impacts from the implementation of AVs and consequence considerations. Since Michigan is the home to one permanent testing site for autonomous vehicles, Michigan was selected as a case study in this paper. By providing an overview of the current implementation of AVs in the U.S., this paper will bring a comprehensive understanding of the adaptation of AVs so far and provide insights into future directions for a better implementation.

Key Words: Adaptation of autonomous vehicles, Highway and Road Update and Rehabilitation, Implementation of Legislative Regulations

Introduction

Autonomous Vehicles (AV) are cars that guide themselves without human control. In other words, it is a computer, GPS, sensor, and augmented reality-based vehicle that is made to move and function on its own. This type of vehicle is being said to be our future of transportation systems (Nikitas et.al. 2017). Bullis (2014) has mentioned, “self-driving will add benefits to our whole society, such as providing transportation for people who are otherwise not able to drive because of age or physical impairment, that is both exciting and meaningful”. There are six levels of autonomy as follow: level 0: all major systems are controlled by humans; level 1: certain systems, such as cruise control or automatic braking, may be controlled by the car, one at a time; level 2: the car offers at least two simultaneous automated functions, like acceleration and steering, but requires humans for safe operation; level 3; the car can manage all safety-critical functions under certain conditions, but the driver is expected to take over when alerted; level 4; the car is fully-autonomous in some driving scenarios, though not all; and level 5; the car is completely capable of self-driving in every situation

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(Cooke 2018). Among six levels of autonomy, AVs with levels two and three runs in our current community, and they could be reached to levels four and five in the coming years.

The technology used in AVs is similar yet different from conventional cars. The types of technology used for AVs are sensors, connectivity, and software/control algorithms. Mattern (2017) mentioned that "Some of them have redundant front cameras that cover different visual depths and angles so that they can simultaneously detect nearby lane markers, construction signs on the side of the road, and streetlights in the distance. Radar sensors, unimpeded by weather, track the distance, size, speed, and trajectory of objects that may intersect the vehicle's path, and ultrasonic sensors offer close-range detection, which is particularly useful when parking" (Mattern 2017). To implement AVs into our current transportation system, it is imperative to plan to update existing transportation systems in the U.S. This will in turn help the adaptation in a smoother transition period. However, as of today, it is not understood well how this transition will be because the needs have not fully been defined. With the growth of AVs in the U.S., there were a lot of attempts across the states to implement AV and amend legislation related to AV. This paper focused on identifying the legislation status in the U.S with a comparison of different states and exploring impacts and considerations for AV adaption in Michigan as a case study.

Literature Review

Since AV technology has been considered an emerging trend in the transportation area, many researchers have been studying the adoption of AVs in terms of their mobility, environmental impacts, and possible concerns. By conducting a literature review, Golbabei et al (2020) examined and classified individual predictors of public acceptance and intention of AVs. Then, they developed a conceptual framework based on these individual factors to illustrate public attitudes towards AVs. From this study, they have identified that the key individual factors are demographic, psychological, and mobility behavior characteristics and the finding reveal those public perceptions and intentions are varied among different socio-demographic cohorts (Golbabei et al. 2020). Similarly, another research studied the individual level AV adoption and timing process by considering the psycho-social factors of driving control, mobility control, safety concerns, and tech-savviness (Asmussent et al. 2020). The conclusion of the study emphasizes that the adoption of AVs should be examined from a psychosocial perspective (Asmussent et al. 2020). By conducting a survey of 391 participants and analyzing the data using structural equation modeling (SEM), Dirsehan and Can (2020) examined the adoption attitudes of individuals toward AVs in terms of trust and sustainability concerns, and they confirmed that the participants' intention to use the AVs depends on how useful it is rather than how easy it is to use. Moreover, this study showed that sustainability concerns and trust have a significant effect on the behavior intention of AVs (Birsehen and Can 2020). There are some studies focused on the impacts of AVs. Greenblatt and Shaheen (2015) reviewed the history, current developments, and projected future trends and environmental impacts of AVs as well as its on-demand mobility and potential synergies. It was mentioned that shared AVs could become a major public transportation facilitating accessibility among a wide range of sociodemographic groups, high efficiency, small size, affordability, and very low GHG emissions, a wide range of land uses (Greenblatt and Shaheen 2015). In Litman's study, the result of the analysis shows that Level 5 AVs may be commercially available and legal to use in some jurisdictions by the late 2020s, but this will require high initial costs and limit performance (Litman 2020).

AV Legislations in the U.S.

Many researchers forecast that there will be approximately 8 million autonomous or semi-autonomous vehicles on the road by 2025. Each year, the number of states considering legislation related to AVs has gradually increased. This warns the government of the potential impacts of AV technology socially and environmentally across the U.S. Before AVs become widespread, it is essential to analyze the policy implications and legislation of AVs with proper and thorough planning, especially with in-depth analysis of conflicts and disruptive impacts. Especially, regulating vehicle capabilities, human factors, and insurance requirements are factors that should be considered by policymakers (Anderson et al. 2014). These include examining liability changes for insurance in the manufacturer versus personal level and understanding the impacts of inconsistent state regulations related to AVs. Additionally, it is also important to examine the overlaps in legislation between federal, state, and even local laws.

Currently, 15 states enacted 18 AV bills, and 33 and 20 states introduced legislation in 2017 and 2016, respectively. Twenty-nine states (i.e., Alabama, Arkansas, California, Colorado, Connecticut, Florida, Georgia, Illinois, Indiana, Kentucky, Louisiana, Maine, Michigan, Mississippi, Nebraska, New York, Nevada, North Carolina, North Dakota, Oregon, Pennsylvania, South Carolina, Tennessee, Texas, Utah, Virginia, Vermont, Washington, and Wisconsin) and Washington D.C. have enacted legislation related to AVs. Governors in Arizona, Delaware, Hawaii, Idaho, Illinois, Maine, Massachusetts, Minnesota, Ohio, Washington, and Wisconsin have issued executive orders related to AVs.

Since 2016, the U.S. Department of Transportation (DOT) has published three reports regarding federal AV policies. These reports include best practices of vehicle regulation including a set of voluntary, publicly available self-assessments by automakers representing how they are building safety into their vehicles, and a proposal to modify the current system of granting exemptions from federal safety standards (Canis 2019). However, most importantly, level 4 and 5 AVs are not aligned with the existing regulations. Therefore, the implementation of local and federal guidelines and regulatory standards, as well as a legal framework for AVs is challenging (Nyashin 2018). Even though there has been recent keen interest in AV legislation, as part of the Endless Frontier Act, Congress has not passed AV legislation thus far. The legislation did not pass the 115th Congress due to disagreements on several key issues (Canis 2019). As a result, now the nation is under an uncertain regulatory environment and lacks a clear path to AV deployment.

Figure 1 presents the states in the U.S. with their legislation status. As shown here, 30 states have enacted the legislation, 5 states have executive orders, and five states both enacted legislation and had executive orders. The current legislation status of the five states given in Figure 1 (i.e., California, Arizona, Florida, Washington D.C., and Michigan) was examined in this research. Among these states, Michigan permitted the testing of AVs in 2013, while the other states, Nevada, Florida, and Arizona permitted 2011, 2012, and 2015 respectively. Also, Michigan allowed the operation of AVs without a person in a vehicle in 2016, and Nevada was allowed this in 2017. Florida also allowed driverless AVs on the public road in 2019. Furthermore, Michigan is a state that addresses the liability of the vehicle manufacturer in 2013 and limited the liability of damages resulting from modifications made to an AV in 2014. Table 1 shows the chronologic orders in legislations for selected four states, Nevada, California, DC, and Florida, and Table 2 provides the legislative orders for Michigan.

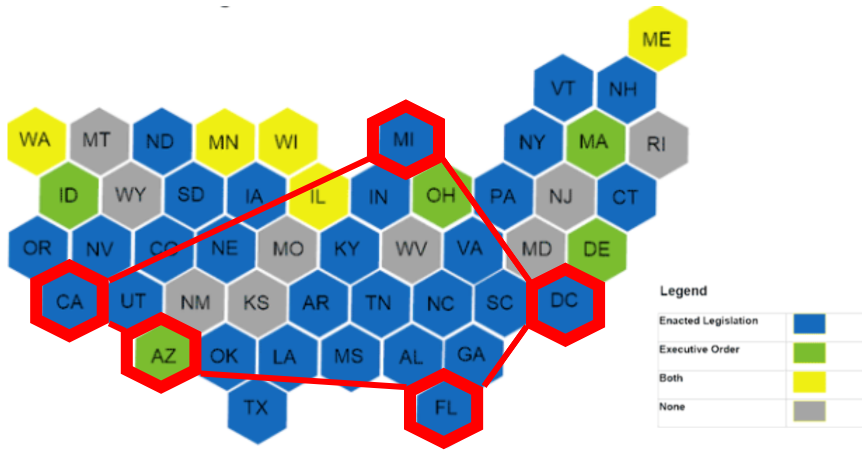

Figure 1. States with AV Enacted Legislation and Executive Orders (NCSL, 2021)

Table 1

Chronologic Orders in Legislations for the Selected States

Nevada	
2011	The first state to authorize the operation of AVs.
	Directed DMV to adopt rules for license endorsement, operation, and safety.
2013	Required proof of insurance from AV operators and that the vehicle meets state standards.
2016	Issued nation's first av-restricted driver license.
2017	The first fully autonomous shuttle operating on public streets in the US.
	Allowed use of autonomous platooning on highways. Required crashes be reported to the DMV within 10 days of resulting in damages over $750.
	Allowed a fine of up to $2,500 for violations of AV regulations.
	Allowed fully autonomous vehicles without a human operator.
	Specified that the following distance rule does not apply to vehicles in a platoon.
	Imposed an excise tax on autonomous vehicles used for transportation services.
	Permitted AV use by carriers and taxi companies under conditions.
2021	Fully autonomous vehicle – Enacted.
Florida	
2012	Declared legislative intent to encourage the development, testing, and operation AVs. - Determined that the state would not prohibit/regulate the testing/operation of AVs. - Directed for additional legislation for the safe testing and operation of AVs.
2016	Permitted operation of AVs on roads by individuals with a valid driver's license.
	Required a study on the use and operation of autonomous truck platooning technology and allowed a pilot project once completed

2019	Driverless AVs allowed on public roads
2021	Autonomous vehicles operation on public - Enacted
District of Columbia	
2013	Required a human driver to be prepared to take control, restricted conversion to recent vehicles, and addressed the liability of the original manufacturer.
2018	Gave its Department of Transportation one year to have a study publicly available that evaluates and makes recommendations regarding AVs
California	
2012	Required the Department of Highway Patrol to establish safety standards and performance requirements to ensure the safe operation and testing of AVs.
2014	DMV autonomous vehicle tester program was established.
2016	Allowed to test autonomous vehicles that did not have steering wheels, brake pedals, gas pedals, or an operator inside the vehicle.
2017	Requested that its DOT use funds from its Road Maintenance and Rehabilitation Program advance technologies accommodate advanced automotive technologies.
	Three bills regarding autonomous vehicles: -Extended the date that autonomous test vehicles could travel with a limit. -Authorized to test AVs without a driver in the driver's seat, steering wheel, etc. -Repealed the requirement to operate an AV without a driver and etc.
2018:	-AV tester driverless program is established Vehicle testing, enacted -Authorized to impose a tax on each ride originating in the City or County. -Authorizes the City and County to set a lower tax rate for net rider fares for a ride
2019	Vehicle testing is enacted

Table 2

Chronologic Orders in Legislations for Michigan

Michigan	
2013	Permitted testing of automated vehicles under conditions and addressed the liability of the vehicle manufacturer.
2014	Limited liability of the manufacturer for damages resulting from modifications made to an automated vehicle.
2016	Open operation of CAVs testing. On-demand AV networks link passengers to transportation options
	-Allowed autonomous vehicles under certain conditions. Allowed operation without a person in the autonomous vehicle. -Specified that the requirement that vehicles maintain a minimum 500 feet following distance doesn't apply to vehicles in a platoon. - Allowed mobility research centers for automated technology testing. Provided immunity for automated technology manufacturers when modifications are made without consent.
2018	Established state infrastructure council to collect data on infrastructure system
2020	Created Michigan office of future mobility

The Impacts of Autonomous Vehicles Implementations in Michigan

With the downfall in the automobile industry, Michigan had experienced a huge economic crisis through the twentieth century. Now, by implementing upcoming technology and AVs, it is hoping that Michigan comes back to its glory days. For such a turn, it is needed to improve and modernize the infrastructure in Michigan. Indeed, it has prospected that Michigan's infrastructural system will be improved and ready for the next generation transportation formation with the new coming infrastructure bill. While rehabilitating the roads, highways, and bridges, technology implementation should also be taken as a part of the process as well as connections and access to charger stations. In other words, the transportation landscape in cities in Michigan should be redesigned with the consideration of new technology.

The current main roads in Michigan's cities, especially in Detroit, are usually multilane in each direction with a turn lane in the center. At each intersection, there is a traffic signal that directs right turns, left turns, straight through traffic, and pedestrians, and the average traffic signal cycle is 120 seconds long. The main road usually gets 60 seconds or more, then, the minor street and pedestrians split the remaining time. Modern traffic signals use loop detectors or video detection to keep the traffic on the main roads flowing until one or two cars are waiting on the minor cross street. The introduction of high automated or fully automated vehicles will make these traffic signals obsolete. It will take forty years that traffic signals to be phased out, but the operation will change to meet the demand for autonomous vehicles. Autonomous vehicles will need to communicate with traffic signals to let groups or platoons of cars through. Presently traffic signal timings are determined by computer modeling programs. In the future, these programs will need to be adapted to communicate and coordinate with autonomous vehicles to keep traffic flowing.

In addition, roadways will be reconfigured for pickup and drop-off zones. It could be either one continuous lane or a block of on-street parking converted into a pickup area like a bus stop. Therefore, these bus stops will become multi-uses as autonomous vehicles are introduced. With increased uses of AVs, the bus stops will be improved, from a sign next to the road or a small shelter to larger stations or waiting areas. This will make businesses want to be located near transit stops due to the volume of people passing by. Approximately 100 years ago, road signs started to become standardized. As autonomous vehicles become predominant, these signs should be restructured and implemented with the needs. However, it is difficult to predict all needs before autonomous vehicles are fully implemented (Shladover, 2018).

Furthermore, one of the important areas is the implementation of legislative regulations. As autonomous vehicles are introduced, new laws and customs will also be introduced to operate the system smoothly and efficiently. However, there are many uncertainties regarding what should be revised such as open container laws, or over the .08 limit still getting a DUI. For now, these laws are still in place because a driver may need to take control of the vehicles (Shladover, 2018). When cars are fully automated and there is no need for driver interaction, then, the judicial system should determine whether this law still applies to the circumstances. Autonomous vehicles may have dedicated lanes, but this will be problematic when drivers need to utilize the lane for passing or traveling if there is no traffic in the AV's lanes. For this situation, police cameras could be installed to enforce lane laws, but pushback is also be expected. Moreover, the lane width for AVs can be reduced, since they are more capable of staying in the center of the lane than human drivers. Narrower lanes will leave more room for sidewalks, trees, bike lanes, light rail trains, and restaurant patios.

The effort of Michigan on AV implementation

As Michigan was hit by an economic crisis about a decade ago, there are still traces of the collapse in various areas. Historically, Michigan has been the leader of the automotive industry till the crisis. With the new vehicles and transportation technologies, now, Michigan is trying to be a part of the new generation automotive industry. However, there are still existing problems that may take a long period to address. Roads and highways in Michigan have been in poor conditions for a long time. Since the transportation system plays an important role in economic growth, such badly shaped roads disadvantage MI's economic growth. People working in Detroit are commonly living in the outside circle of the city due to various reasons such as safety and educational preferences for kids, so commuting routes and transportation grid are critical in the state re-development. Traffic congestion can be tracked by the level of service during peak hours (Highway Capacity Manual 2000). Also, parking has become an issue in the city. However, there is much uncertainty if the need for parking will increase, decrease, or be shifted to the outer ring around downtown Detroit with AV technology. Therefore, it is needed to see which theory is appropriate for a parking spot inventory as a baseline.

Michigan is already home to one of the permanent testing sites for AVs, with another slate to be open in the near future. In Figure 2, some samples are given. The first facility given in Figure 2.a, opened in 2015 by the University of Michigan, is called Mcity. This is a 32-acre site in Ann Arbor, Michigan that claims to be the world's first controlled environment to specifically test the potential of connected and automated vehicle technologies that will bring driverless cars to the mass market. University of Michigan Transportation Research Institute broke ground in early 2014 on the U.S. DOT funded Michigan Mobility Transformation Center at Ann Arbor, Michigan: "The $30 million simulated city, built like a movie set on 32 acres, will test connected vehicle and infrastructure technology to simulate crash scenarios in a realistic environment." Michigan has strongly tackled that perception, with new initiatives like Planet M, a state-run organization, investors, and research pilots by connecting them to the state's existing automotive environment. Then, the state launched the way of establishing the leading test facilities for AV in Ypsilanti such as the American Center for Mobility as seen in Figure 2.b. There's another rising mobility research facility between Ann Arbor and Detroit, that has the future headquarters of Ford's AVs department in Dearborn, Detroit, given in Figure 3. In this complex, AV research and implementation have been carried. In addition, Michigan State University (MSU) is testing these vehicles, patrolled within 80 miles roads. Many research activities and proposals are being considered and carried out by supporting groups and businesses.

a. Mcity is a 32-acre simulated urban and suburban environment

b. American Center for Mobility

Figure 2. Sample Developments in Michigan: MCity and American Center for Mobility

Figure 3. Ford World Headquarters in Dearborn MI

Conclusion

There is a big expectation from AVs that will greatly improve our daily lives, environment, and productivity. AVs will bring positive benefits such as fewer vehicle crashes due to the decrease in driver faults, increase in mobility for young, elderly, and disabled, the ease of congestion, reduced the costs of travel time, and more time doing other activities than driving, alternate energy sources, and less parking structures and lots. However, it is important to consider various aspects carefully including planning and implementations before the world is ready to see AVs on the roadways, highways, and infrastructures. To cope with upcoming AV technology, this paper provides detailed information and background of legislation aspects of AVs and investigates the implementation of AV in the transportation system Also, Michigan was selected as a case study to explore the impacts of AVs and their effort to implement AVs so far in the state. Since AVs will be the most common transportation tool in the future, the transportation system should be adjusted according to this new technology with all components and implementations.

The legislation is an important part of AVs adaptation. In this research, five different states California, Arizona, Florida, Washington D.C., and Michigan were investigated and compared with each other's status. Important dates were tabulated for these states which provide an easy comparison in different states. Providing specific dates regarding legislation of AVs in five states gives an insight into the future of the AVs in these states. In addition, Michigan was investigated as a case study that has lots of opportunities with coming AV technology. Detroit's economic status is expected to recover more quickly in the next couple of years because of the high shift of technology coming with autonomous vehicles. The unemployment rate in Detroit will come down since many initiatives by auto companies located in Michigan, and other companies are in developing the neighborhoods of Detroit for coping with the next generation of technology. Ford Motor Company is working in renovating their development and research Center in Dearborn at an estimated cost of $1.2 Billion with 48,000 employees. One of the main components of this investment is to enhance AV research and implementation. It also includes building new parking lots and transits. As autonomous vehicles are introduced to the community, new laws and customs should be introduced. Consequently, the technical phase should go with the legislation hand to hand. It is expected that these efforts will lead to a successful implementation of AVs in the state.

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