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State of Wyoming
Department of Transportation

Impacts of Cooperative Automated Transportation on Wyoming Highway Infrastructure

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The primary objectives of this research are to synthesize the state-of-the-practice of existing national, state, and local agencies regulations and legislations related to AVs/CAVs, to identify infrastructure, traffic management policy, roadway design and standardization needs in order to facilitate deployment of autonomous driving, to investigate requirements for workforce development as well as changes needed for engineering curriculum for the era of autonomous driving. The results of this research will provide important implementable guidelines for WYDOT decision makers to support the development of a strategic plan for CAT activities in Wyoming.
The recommendations in this report include: the development of Wyoming AV regulations, legislation, as well as guidance for testing and platooning procedures, the potential impacts of AVs on the physical and multimodal infrastructure, changes in traffic control devices and warrants for traffic signals.</td></tr>
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SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
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ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5(F-32)/9 or (F-32)/1.8	Celsius	°C
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	Newtons	N
lbf/in^2	poundforce per square inch	6.89	Kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	Inches	in
m	meters	3.28	Feet	ft
m	meters	1.09	Yards	yd
km	kilometers	0.621	Miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	Acres	ac
km^2	Square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	oz
L	liters	0.264	Gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	Ounces	oz
kg	kilograms	2.202	Pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	Poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lb/in^2

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LIST OF ABBREVIATIONS

Acronym	Description
AAMVA	American Association of Motor Vehicle Administrators
ADAS	Advanced Driver Assistance Systems
ADS	Automated Driving Systems
AV	Autonomous/Automated Vehicle
CAT	Cooperative Autonomous/Automated Transportation
CAV	Connected and Autonomous/Automated Vehicle
CV	Connected Vehicles
DOT	Department of Transportation
DMV	Department of Motor Vehicles
EMS	Emergency Medical Services
FHWA	Federal Highway Administration
FMVSS	Federal Motor Vehicle Safety Standards
GFI	Goodness-of-Fit
IICS	Intelligent Intersection Control System
ITS	Intelligent Transportation Systems
MOOC	Massive Open Online Course
MTC	Markings Technical Committee
MUTCD	Manual on Uniform Traffic Control Devices
NACTO	National Association of City Transportation Officials
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NCUTCD	National Committee on Uniform Traffic Control Devices
OCR	Optical Character Recognition
ODD	Operational Design Domain
TCD	Traffic Control Devices
TSR	Traffic Signs Recognition
SAE	Society of Automotive Engineers
SEM	Structural Equation Model,
VMT	Vehicle Miles Traveled
WYDOT	Wyoming Department of Transportation

EXECUTIVE SUMMARY

Since the invention of the automobile, disruptive technologies and road users' behaviors have continually demanded highway infrastructure adaptations. While it is understandable that the highway infrastructure industry is growing at a much slower pace than the automotive industry, the rapid advancement in transportation technologies requires national and local transportation agencies to keep up with these changes and their impacts on infrastructure to benefit from and prepare for these new innovations. In comparison to traditional human-driven vehicles, Cooperative Autonomous/Automated Transportation (CAT) has the potential to bring about transformative safety, mobility, human productivity, fuel consumption, and environmental benefits to the surface transportation system. These benefits mainly include: drastic reduction of the number of fatal crashes that are caused by human errors; driving opportunities to people who are not able or are unwilling to drive; provide commuters a quicker and less stressful commuting experience, thus enhancing human productivity; reduce needs for parking at congested areas due to the ability of vehicles to return to the origin; improve traffic operations and fuel efficiency by vehicle-platooning technology, especially for commercial heavy vehicles, and the environmental benefits from the improved operations of traffic. Although reaching high market penetration rates of CAVs and their enabling/supporting infrastructure in the near future is speculative, it is believed that CAT will have a significant impact on the future of transportation.

While vehicle and highway automation might bring tremendous benefits to surface transportation, it may pose unprecedented challenges for transportation agencies due to a lot of uncertainties related to Autonomous/Automated Vehicle (AV) interactions with highway infrastructure. A thorough understanding of the challenges involved in the deployment and operation of CAT in Wyoming, and the research needs to conquer these challenges will be crucial for Wyoming Department of Transportation (WYDOT) to pave the way to the era of autonomous driving. The primary objectives of this research are to synthesize the state-of-the-

practice of existing national, state, and local agencies regulations and legislations related to AVs/CAVs; to identify infrastructure, traffic management policy, roadway design and standardization needs in order to facilitate deployment of autonomous driving; and to investigate requirements for workforce development, as well as changes needed for engineering curriculum for the era of autonomous driving. The results of this research will provide important implementable guidelines for WYDOT decision makers to support the development of a strategic plan for CAT activities in Wyoming.

Synthesis of Wyoming AV Regulations and Legislations

This task was aimed at conducting a thorough review of the existing national and state level regulations and legislations related to autonomous driving and AV crash reporting system. From the review of the legislations across the United States (U.S.), it was found that 41 states and the District of Columbia have either passed legislation, issued executive orders, or announced initiatives to accommodate AVs on public roads to date. Recently, Wyoming has also introduced a bill in the Wyoming's legislature to regularize the operation of AVs in the state. The review of the legislations and regulations also revealed that some states, such as California, Florida, Michigan, Nevada, and New Hampshire, provide more comprehensive regulations compared to other states. Following the regulations of these states, a comparison is drawn with the Wyoming bill and recommendations made for future amendment to the bill. After the implementation of the regulations across the states, the various AV related activities and projects of the industry manufacturers or the state Departments of Transportation (DOT) are also summarized in this section.

The recommendations are aimed to provide risk management strategies for on-road testing and to clarify federal, state, and local responsibilities to ensure safety prior to testing and full deployment of CAT.

Impacts on Infrastructure and Roadway Design

In this section, the impact on infrastructure, roadway design, and traffic control devices is discussed. It was determined from the review that the major impact on physical infrastructure will be from the increased concentrated loading due to platooning. Platooning is the coordinated movement of a series of vehicles at shorter gaps using connected vehicle technologies. Platooning allows vehicles to travel with minimal headway and lateral offset. As a result, there has been proven impact of accelerated pavement deterioration due to such operations. For bridges and culverts, which are traditionally designed for a single truck or a truck-trailer, some of these structures may not be adequate in taking the increased dynamic loading of platoon operations. To negate such impacts, or at least minimize the impacts in the short-term, it is recommended to improve the maintenance efforts of the state agencies. When the penetration rate of AVs increases it might be necessary to re-evaluate the design standards of the structures.

Research shows that the powerful sensor capabilities of AVs can be utilized to provide more conservative roadway design in terms of reduced sight distances, shorter crest, and sag lengths of vertical curves. However, the researchers are careful in recommending these designs as they believe more comprehensive study in this area is required as it is an emerging area of research. One common consensus was that, irrespective of the advances in technology, vision sensors of AVs are subject to the same limitations as human sight in darkness and adverse weather conditions. Although some emerging technologies, such as smart pavements and smart roads, may solve these issues with sensors, the implementation of these technologies is far from becoming a reality anytime soon.

Impacts on Traffic Control Devices

Identifying the infrastructure needs for CAVs is essential to help local agencies and DOTs to get prepared to accommodate such emerging technologies. Road furniture with a focus on items that provide warnings, regulations, directional information, and operation where the main focus of researchers and CAV manufacturers is to provide an efficient Vehicle-to-Infrastructure

(V2I) communication. Road marking, signs, and signals are the three main categories that transportation agencies need to provide extra attention to, as CAVs heavily rely on these items for safe operation.

Uniformity and quality of traffic control devices are considered the most challenging issue that face the deployment of CAVs. In coordination with several automotive industry associations, the National Committee on Uniform Traffic Control Devices (NCUTCD) aimed to identify the modifications needed for the existing traffic control devices to accommodate the operation of CAVs. Traffic control devices (pavement marking, signs, and signals) needs are detailed in this report as well as the current and future recommendations.

Impact of CAT on Workforce and Engineering Curriculum

It is crucial to equip undergraduate, graduate students, and professionals with the requisite skills to adequately prepare them for careers related to Connected and Autonomous/Automated Vehicle (CAV) technologies. Ongoing efforts are underway to integrate CAV technologies into engineering curricula, including dedicated courses that acknowledge the need for specialized education. The recommendation is to augment these initiatives by incorporating additional CAV-focused transportation and simulation courses for both graduate and undergraduate engineering students, emphasizing the integration of fundamental transportation engineering with CAV technologies. Proposing a proactive approach, by introducing a Massive Open Online Course (MOOC) platform for universities, as well as online programs. This platform would facilitate independent learning, enabling students to select courses tailored to provide the essential knowledge and skills for industrial occupations. The overarching goal is to ensure that the workforce remains adaptable and well-prepared for the dynamic landscape of autonomous and connected technologies in the future.

Transportation Planning

Incorporating Autonomous/Automated Vehicles (AVs) into transportation planning studies is imperative to comprehend and address their potential impacts on travel and land use. Researchers have examined and synthesized the transportation planning implications of AVs. These vehicles are expected to alleviate various daily driving limitations (e.g., parking challenges) as they can autonomously manage these tasks. This enhanced convenience is likely to make AV-related modes more appealing than existing alternatives. The potential for increased convenience and the opportunity for more productive use of time in autonomous vehicles may augment individuals' tolerance for extended in-vehicle travel times. Moreover, the low reaction times and increased awareness of their surroundings, AVs are anticipated to utilize road space more efficiently than human drivers. These factors have a significant effect on the four transportation planning phases; 1) trip generation, 2) trip distribution, 3) mode choice, and 4) trip assignment

Public Acceptance

A survey instrument was developed to capture the perspectives of Wyoming residents concerning CAV and autonomous driving systems. Analysis was conducted on a dataset comprising of 1062 responses. Participants consistently highlighted the perceived advantages of CAV technologies. Employing a Structural Equation Model (SEM), the findings demonstrated that the public's acceptance of CAVs was predominantly shaped by their endorsement of CAVs in Emergency Medical Services (EMS) and apprehensions regarding the privacy of personal data. This acceptance was indirectly affected by the public's confidence in CAV technology, coupled with considerations related to operational liability and performance.

Original Equipment Manufacturers (OEMs) Safety Approach

Autonomous vehicle manufacturers are recommended to integrate safety considerations into the design of their systems. While there is currently no universally accepted standard for assessing manufacturers' adherence to safety elements, it is expected that manufacturers articulate and document their procedures for the evaluation, testing, and validation of diverse system elements.

Recommendations

The comprehensive integration of cooperative automated transportation into Wyoming's highway infrastructure is anticipated to have broad-ranging effects, including improvements in efficiency, safety, economic dynamics, and environmental considerations. To seamlessly incorporate CAV technologies into the state's transportation framework, a strategic approach is required, involving meticulous planning, essential infrastructure upgrades, and the formulation of expert policies that accommodate the evolving automated systems. Additionally, ongoing monitoring is crucial to assess system performance and ensure alignment with emerging trends. The key to success lies in adaptability and responsiveness to evolving CAV technologies, enabling Wyoming to fully leverage the benefits of cooperative automated transportation while proactively addressing and mitigating potential challenges inherent in this transformative process.

Chapter 1 INTRODUCTION

BACKGROUND

User acceptance, integration, and use or modern inventions could be synthesized using adoption of technology. It is measured by the percentage of the U.S. households that access or adopt the technology. Projecting these percentages over time will provide adoption rates for these technologies. Figure 1 shows the adoption rates for several inventions from 1900 till 2005.

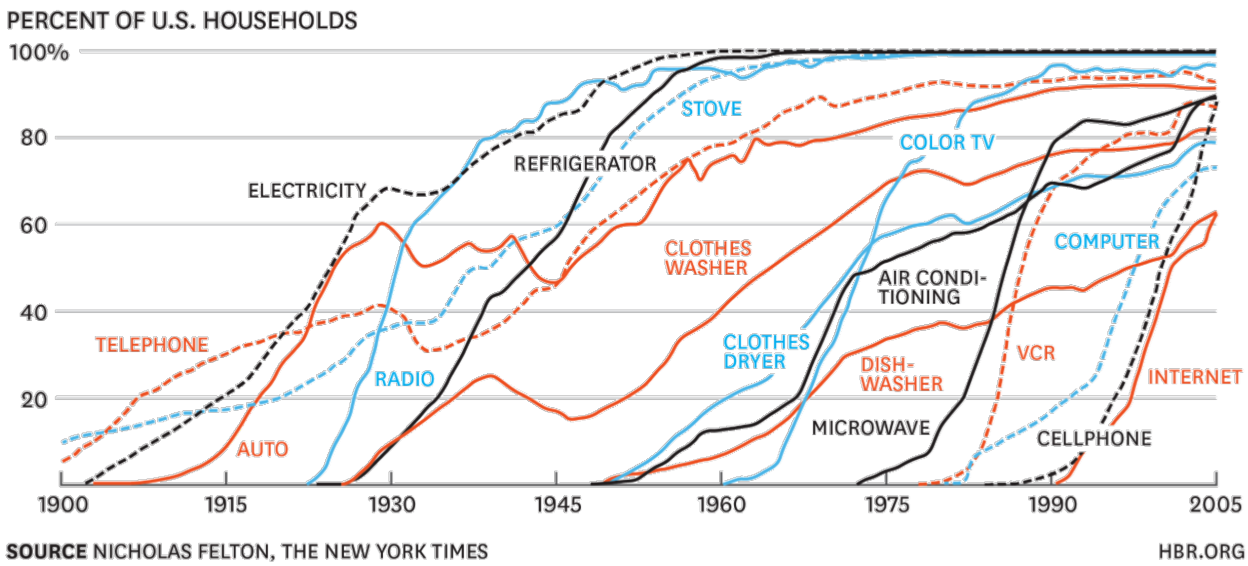


Figure 1 Consumption of Technology (Source of the figure: Nicholas Felton, the New York Times)

Some of the inventions had fast adoption rates, such as color television and computer, while others had a slower adoption rate, such as telephone. Among the technologies that had a high acceptance rate by users were vehicles and vehicle technologies. This implies that the adoption of automated driving systems (ADS) will have similar adoption rates as other vehicular technologies. It could be estimated from Figure 2 that adoption of ADS and advanced driver assistance systems (ADAS) technologies might take up to 25 years for full adoption. It is expected that 50 percent of U.S. vehicle fleet would have AVs by 2050 [1], [2]. Accordingly, transportation agencies should be prepared for such emerging technologies by identifying the needs to accommodate autonomous vehicles. Legislations, regulations, infrastructure, traffic control devices, ITS, and road management will be impacted by these technologies. Identifying what areas that will be impacted by CAVs, how they will be impacted, how soon they will be impacted, and which locations will be first impacted will help in having a smooth transition from human-driven vehicles into fully autonomous vehicles.

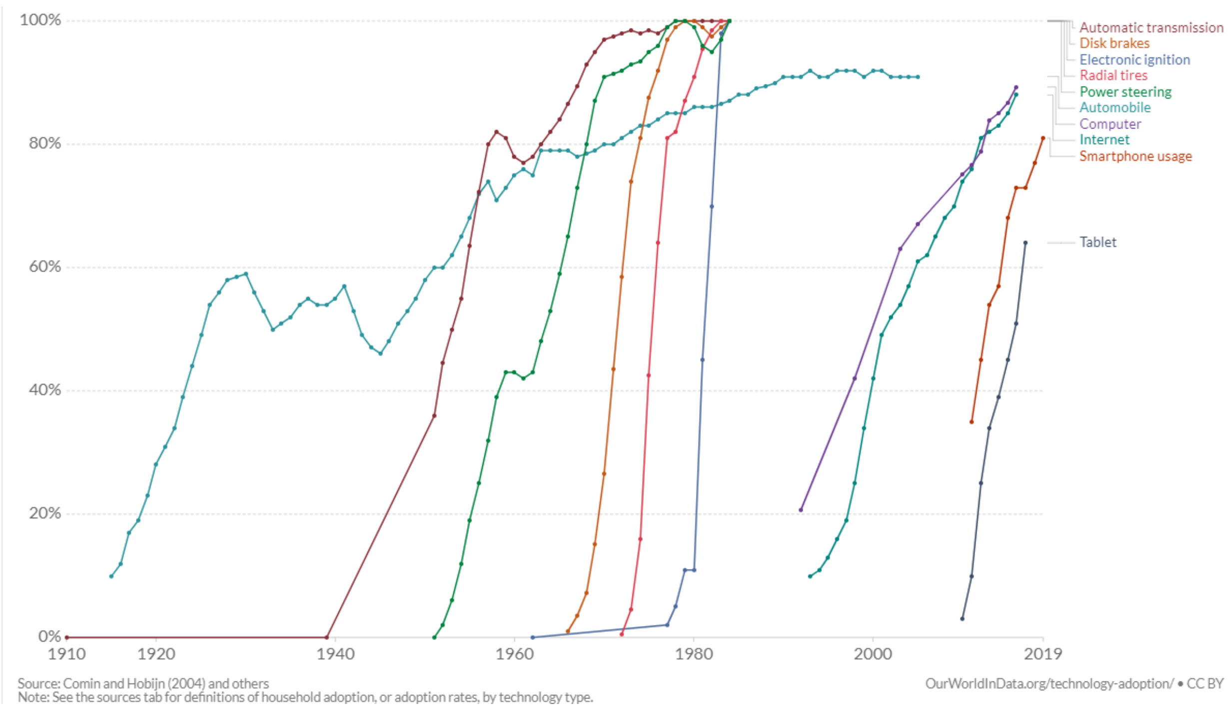


Figure 2 Consumption of Vehicle Technologies vs. Recent Technologies. Source: Comin and Hobijn (2004) and others.

According to the Society of Automotive Engineers (SAE) Standard J3016 [3], six levels of driving automation (Level 0 to Level 5) were defined, as illustrated in Figure 3:

- Level 0- no automation: the driver is in complete control of the vehicle at all times.

- Level 1- driver assistance: vehicles assist the driver by automating one of the following primary control functions: longitudinal control (speed, braking, and acceleration) or lateral control (steering).
- Level 2 – occasional self-driving: vehicles can automate both longitudinal and lateral control.
- Level 3 – limited self-driving: vehicles can operate in an automated manner in a specific area with a driver being ready to take control if needed.
- Level 4 – full self-driving under certain conditions: vehicles expand on level 3 and can perform all driving tasks under certain conditions.
- Level 5 – full self-driving under all conditions: vehicles can operate in an automated manner in all areas, at all times, without the need for a driver to be available to take control.

Based on NHTSA's guidance, SAE automation Level 3 and above ADSs will be the main future research emphasis [4].

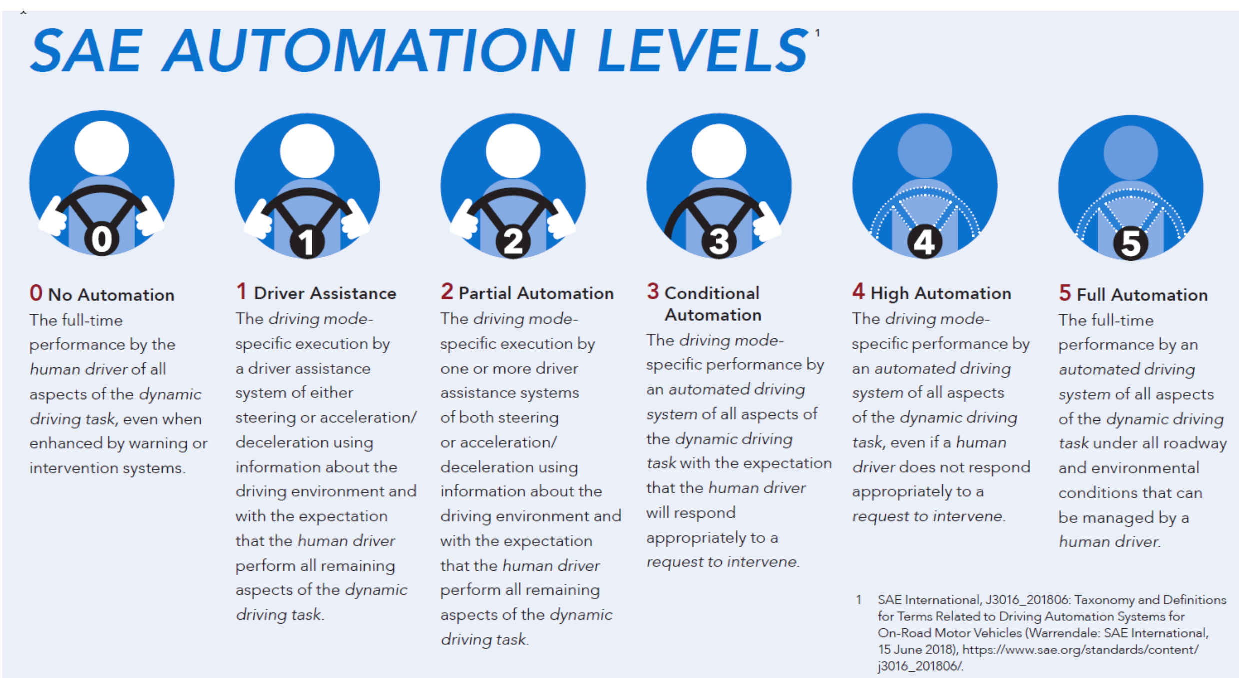


Figure 3 Summary of SAE Standard J3016 Levels of Driving Automation. Source: SAE, 2019.

This study will help in addressing and mitigating the potential impacts of AVs on Wyoming's surface transportation system. Recommendations to WYDOT on the impacts of CAV on highway infrastructure, development of Wyoming CAT regulations, legislation, as well as updated crash reporting system; requirements to workforce and engineering curriculum development; potential updates to the WYDOT Road Design Manual to accommodate the future deployment of CAT, upgrades of regional transportation planning models, warrants for traffic signals and other traffic control device, and framework of managing of data management.

PROBLEM STATEMENT

Since the invention of the automobile, disruptive technologies and road users' behaviors have continually demanded highway infrastructure adaptations. While it is understandable that the highway infrastructure industry is growing at a much slower pace than the automotive industry, the rapid advancement in transportation technologies requires national and local transportation agencies to keep up with these changes and their impacts on infrastructure to benefit from and prepare for these new innovations. CAT, including Connected Vehicles (CVs), Automated Vehicles (AVs), and CAVs have been the main focus of the automotive industry in the recent years [5], [6]. This era of cooperative automated transportation will transform people's lives in many ways. In comparison to traditional human-driven vehicles, CAT has the potential to bring about transformative safety, mobility, human productivity, fuel consumption, and environmental benefits to the surface transportation system [7]. These benefits mainly include; drastic reduction of the number of fatal crashes that are caused by human errors; driving opportunities to people who are not able, or unwilling to drive; provide commuters a quicker and less stressful commuting experience, thus enhancing human productivity; reduce needs for parking at congested areas due to the ability of vehicles to return to the origin; improve traffic operations and fuel efficiency by vehicle-platooning technology, especially for commercial heavy vehicles, and the environmental benefits from the improved operations of traffic. Although reaching high market penetration rates of CAVs and their enabling/ supporting infrastructure in the near future is speculative, it is believed that CAT will have a significant impact on the future of transportation.

RESEARCH TASKS

The primary objectives of this research are to synthesize the state-of-the-practice of existing national, state, and local agencies regulations and legislations related to AVs/CAVs, to identify infrastructure, traffic management policy, roadway design and standardization needs in order to facilitate deployment of autonomous driving, to investigate requirements for workforce development as well as changes needed for engineering curriculum for the era of autonomous driving. The results of this research will provide important implementable guidelines for WYDOT decision makers to support the development of a strategic plan for CAT activities in Wyoming.

REPORT STRUCTURE

This report is structured as follows:

Chapter 1 presents a brief introduction to vehicle automation followed by the research tasks.

Chapter 2 provides the synthesis of the review carried out on the legislations and regulations, comparisons drawn with the Wyoming bill introduced, and recommendations provided for the missing items in the bill.

Chapter 3 summarizes the findings from the literature on the impacts of CAT on infrastructure, namely the physical infrastructure (pavement, bridges, and culverts), roadway design, traffic control devices, and multimodal infrastructure.

Chapter 4 presents a brief insight into the impacts that CAT will have on the workforce, changes in engineering curriculum, and the driver/operator training.

Chapter 5 provides information about the updates for the transportation planning models to account for CAV technologies.

Chapter 6 describes the on-going effort with the development of a survey questionnaire to capture the user perception of CAT in Wyoming.

Chapter 7 outlines the safety approach of some of the leading industry manufacturers/entities in developing autonomous vehicles for the public use.

Finally, Chapter 8 provides the preliminary recommendations developed from the synthesis of literature carried out so far.

Chapter 2 SYNTHESIS OF AV REGULATIONS AND LEGISLATIONS

As the technology for autonomous driving continues to develop, state DOTs and municipal governments have gradually realized the necessity of addressing the potential impacts of AVs on the road. Without government permits, testing or any kind of operation of AVs on public roads is almost universally illegal. Nevada was the first state to authorize the operation of AVs in 2011. Currently, 41 states and the District of Columbia in the U.S. have either passed legislation, issued executive orders, or announced initiatives to accommodate AVs on public roads.

This chapter summarizes the review of all the legislations, executive orders, or other regulations adopted by the states in order to regularize AV testing or operations. It must be mentioned that some states may have failed or pending legislations pertaining to regulations of AVs or truck platoons. However, those legislations have not been included as part of this review.

NATIONWIDE POLICIES ON AUTOMATED VEHICLE IMPLEMENTATION

An overall summary of the regulations is provided for each state and then the regulations are categorized into various items based on the priority list and legislative recommendations provided in the National Cooperative Highway Research Program (NCHRP) and National Highway Traffic Safety Administration (NHTSA) reports [8], [9]. If a state is missing a particular item, it means that the state does not regulate that item pertaining to AV testing or operation. Appendix B provides the glossary of some key definitions used across the states which are used in this review. In order to clarify what each term means in the respective state's regulations/legislations, separate definitions are provided for some key terms. For example, Alabama defines platoon as "a group of individual commercial truck" and Pennsylvania defines platoon as "a group of motor vehicles, buses, military vehicles or motor carrier vehicles".

Alabama

Alabama has been active in studying AVs since 2016 when it established the Joint Legislative Committee [10]. The 2019, Senate Bill 47provides the Alabama DOT (ALDOT) sole and exclusive jurisdiction over AVs and related technologies, was enacted on April 4, 2024 [11]. To date, Alabama has no laws or regulations related to non-commercial (passenger) AVs.

Full deployment of commercial vehicles

Senate Bill 47, the operation of commercial AVs without a driver inside the vehicle and commercial motor vehicles with teleoperation system were authorized under certain conditions [12]:

- Compliance with applicable federal law and the traffic and motor vehicle laws of the state, applicable laws concerning the capability to safely navigate and negotiate railroad crossings.
- Registered and titled in accordance with the existing laws of the state.
- Compliance with federal motor vehicle safety standards (FMVSS) and bears the required certification label or labels (49 C.F.R. Part 567), including reference to any exemption granted under applicable federal law.
- Able to initiate minimal risk condition in case of vehicle failure.
- Proof of motor vehicle liability coverage in an amount not less than $2 million.
- The owner/lessee is the operator of the vehicle for the purpose of assessing compliance with applicable traffic or motor vehicle laws, including the rules of the road.
- The automated driving system is considered to be licensed to operate the vehicle.

Teleoperation system

A commercial motor vehicle equipped with a teleoperation system is allowed operate without a conventional driver physically present in the vehicle if a remote driver is operating the vehicle and holds the proper class of license required for a conventional driver to operate the vehicle.

The remote driver is considered to be the operator of the vehicle for the purpose of assessing compliance with applicable traffic or motor vehicle laws and for the purpose of any charge for a violation of the Alabama Criminal Code.

Insurance

All commercial AVs being operated in the state must have minimum liability coverage of $2 million.

Crash Liability

For fully autonomous commercial vehicles the owner or lessee is considered the operator of the vehicle for the purpose of assessing compliance with applicable traffic or motor vehicle laws, including the rules of the road.

In the event of a crash involving a commercial motor vehicle equipped with a teleoperation system, the remote driver who is operating the vehicle is subject to all applicable state laws regarding taking test or tests of the remote driver's blood, breath, or urine for the purpose of determining that the person's alcohol concentration, or the presence of other drugs. The remote driver is also subject to the Code of Alabama pertaining to crashes, regardless of the jurisdiction in which the remote driver is physically present.

Crash Reporting

When a crash occurs involving an automated commercial motor vehicle, the vehicle needs to remain on the scene of the crash and the vehicle, owner, a person on behalf of the owner, or operator needs to promptly contact the appropriate law enforcement entities and communicate the information required by existing state laws. This shall satisfy the requirements of the existing state laws regarding crashes.

Driver/Operator Licensing

For fully autonomous commercial vehicles, the automated driving system is considered to be licensed to operate the vehicle.

For teleoperation system, the remote driver is required to hold the proper class of license required for a conventional driver to operate the vehicle.

Truck Platooning

Coordinated truck platoon was defined in 2018 legislation and the trucks with such technology were exempted from the state's following too closely provisions.

Arizona

There is no state law enacted to date to regularize the testing or operation of AVs in the State of Arizona. However, the Governor of Arizona, through Executive Order 2015-09, Self-Driving Vehicle Testing and Piloting in the State of Arizona; Self-Driving Vehicle Oversight Committee, allowed the pilot testing and operation of self-driving vehicles under certain conditions [13]. Executive Order 2018-04, Advancing Autonomous Vehicle Testing and Operating; Prioritizing Public Safety was enacted and it further defined the automation levels and self-driving technologies with the aim to advance AV testing and operation in Arizona and prioritizing public safety [14]. AV entities can begin testing or operation of AVs in Arizona by notifying the Arizona DOT (ADOT) and making sure their vehicles comply with applicable state and federal law [15]. The welcoming nature of Arizona's AV regulatory framework makes it one of the most convenient states for AV testing and deployment.

Full Deployment

AV regulations in Arizona indicate that testing or operation of self-driving vehicles equipped with an automated driving system on public roads of Arizona is allowed following all Federal laws, regulations, and guidelines, all applicable existing state laws, and all regulations and policies set forth by the ADOT and Executive Orders. Testing or operation of vehicles that do not have a person present in the vehicle is allowed only if such vehicles are fully autonomous, and if prior to commencing testing or operation of the fully autonomous vehicles, an Autonomous Vehicle Testing Statement and Certification has been submitted to the ADOT acknowledging:

- Compliance with all applicable Federal law and FMVSS and bears the required certification label(s) including reference to any exemption granted under applicable federal law.
- Able to initiate minimal risk condition in case of vehicle failure.
- Capable of complying with all applicable traffic and motor vehicle safety laws and regulations of the State of Arizona.
- Meets all applicable certificate, title registration, licensing, and insurance requirements.

Arkansas

The operation of AVs on the state roadways, under pilot programs approved by the Arkansas State Highway Commission, was authorized in 2019 [16]. The legislation, HB1561, includes provision of maximum three simultaneous AVs from a single entity to be operated on the Arkansas roadways. The regulations do not differentiate between testing and operation of AVs. As a result, the regulations provided in the legislations govern full deployment.

Full deployment

The operation of an autonomous vehicle or a fully autonomous vehicle is allowed in Arkansas under an autonomous vehicle pilot program approved by the Arkansas State Highway Commission. The AV pilot program was automatically approved 60 days after the date the autonomous vehicle pilot program was submitted to the Arkansas State Highway Commission for approval. The pilot program application must be submitted with the following:

- A statement of the commercial purpose of the autonomous vehicle pilot program.

- Proof of insurance under the Motor Vehicle Safety Responsibility Act for Arkansas.
- A statement acknowledging:
  - compliance with all applicable traffic and motor vehicle safety laws and rules adopted by the Office of Motor Vehicle
  - capability of achieving a reasonably safe state if a failure of the automated driving system occurs that renders the automated driving system unable to perform the entire dynamic driving task.
  - capability of meeting the state requirements when involved in a motor vehicle crash.

Safety Reports

The description of how a fully autonomous vehicle is capable of achieving a reasonably safe state, if a failure of the automated driving system occurs, is also required to be submitted with the pilot program application.

Truck Platooning

Regulations for spacing between vehicles are provided as a minimum of 200 feet. The 2017 legislation, HB1754, defines driver-assistive truck platooning and exempts the vehicles equipped with such technology from the following-too-closely regulations [17].

The general operation of a driver-assistive truck platooning system on a street or highway of this state is allowed if the plan is filed with the Arkansas State Highway Commission. If the plan is not approved within 45 days of submission, then it can be considered approved.

California

California has been the top-ranked state in openness and preparedness for AVs. The state has been quite comprehensive in regulating AVs by enacting several laws that lay out procedures for testing and deployment of AVs. *Senate Bill No. 1298*. 2012, California Autonomous Vehicle Regulations, authorized the operation of an AV on public roads for testing purposes following certain conditions set forth in the legislation and as long as a driver is present to takeover control [18]. The legislation also required the department of motor vehicles (DMV) to adopt rules and regulations for testing and operation of AVs without drivers inside the vehicle. As of September 2020, 60 entities have been issued permits for AV testing with a driver present which include entities such as Apple, Argo AI, BMW, Cruise, Ford, Honda, Waymo, among others [19]. In early 2018, the California DMV approved regulations of testing and public use of fully AVs without drivers to operate on public roads [20]. Currently, as of October 2020, the following entities have been issued permits for driverless AV testing: Autox Technologies Inc., Cruise LLC, Nuro Inc., Waymo LLC, and Zoox Inc. [21]. California is one of the states that have separate regulations for testing and full deployment of AVs.

Full deployment

The deployment of an autonomous vehicle on any public road in California by a manufacturer is subject to the submission and approval of an application for a Permit to Deploy Autonomous Vehicles on Public Streets (form OL 321) with the following requirements:

- Details of the Operational Design Domain (ODD), in which the subject autonomous vehicles are designed to operate, which includes any commonly-occurring or restricted conditions, including but not limited to: snow, fog, black ice, wet road surfaces, construction zones, and geo-fencing by location or road type, under which the vehicles are either designed to be incapable of operating or unable to operate reliably in the autonomous mode or state the mechanism for safely disengaging out of autonomous mode in the event of experiencing conditions outside of its operational design domain.
- The AV is capable of initiating minimal risk condition in case of a failure.
- Certification of compliance with all applicable FMVSS (49 C.F.R. Part 567).
- Consumer or end user education plan for vehicles to be sold or leased to persons other than manufacturer.
- Law enforcement interaction plan.

Testing with driver

A manufacturer is allowed to conduct testing of autonomous vehicles on public roads in California if all of the following requirements are met:

- The manufacturer is conducting the testing.
- Presence of an autonomous vehicle test driver.
- Provide an instrument of insurance in the amount of $5 million.
- Apply and get approved for a Manufacturer's Testing Permit.

Testing without driver

A manufacturer is allowed to conduct testing of autonomous vehicles capable of operating without the presence of a driver inside the vehicle on public roads in California if all of the following requirements are met:

- Provide local authorities and the department with a written notification containing: (1) ODD; (2) list of public roads where testing will occur; (3) testing start date and times of testing; (4) number and type of vehicles; and (5) contact information for the contact person.
- Certification of compliance with:
    - Communication link between the vehicle and the remote operator.
    - Process to display or communicate vehicle owner or operator information in the event of a crash.
    - Compliance with all required FMVSS (49 C.F.R. Part 567).
- Certification of the autonomous vehicles' capabilities to operate without the presence of a driver inside the vehicle and that the autonomous technology meets the description of a level 4 or level 5 automated driving system under SAE standard J3016 (SEP2016).
- The manufacturer is required to provide a copy of a law enforcement interaction plan.
- The manufacturer is required to maintain a training program for its remote operators.

Insurance

A manufacturer, either testing or deploying an AV in California, is required to provide proof of insurance in the amount of $5million in the form of: an instrument of insurance issued by an insurer admitted to issue insurance in California; a surety bond; or a certificate of self-insurance.

Safety Reports

California is the only state to require disengagement reports from manufacturers. It is required for a manufacturer to retain data related to the disengagement of the autonomous mode and submit to the department an annual report summarizing the information. The manufacturers must also submit a certification that the manufacturer has conducted test and validation methods and is satisfied, based on the results of the tests and validations, that the vehicles are safe for deployment on public roads in California. It is also required for a manufacturer who identifies a safety-related defect in their autonomous technology that creates an unreasonable risk to safety to submit to the department a copy of the report prepared in compliance with the timeframe and requirements specified in 49 C.F.R. Part 573.

Operators

Although the regulations allow fully driverless testing or deployment, the manufacturers must certify that a communication link is active between the vehicle and a remote operator to provide information on the vehicle’s location and status and allow two-way communication between the remote operator and any passengers.

Crash Reporting

A manufacturer whose autonomous vehicle, while operating under a Manufacturer's Testing Permit or a Manufacturer's Testing Permit - Driverless Vehicles, is in any manner involved in a collision originating from the operation of the autonomous vehicle on a public road that resulted in the damage of property or in bodily injury or death is required to report the collision to the department, within 10 days after the collision.

Licensing

For testing with drivers, the autonomous vehicle test driver is required to be licensed to drive a motor vehicle for the three years immediately preceding application to the DMV .

Training Programs

A manufacturer conducting testing of AVs on public roads is required to maintain a training program for its autonomous vehicle test drivers and provide the DMV with a course outline and description of the autonomous vehicle test driver training program.

The manufacturer is also required to maintain a training program for its remote operators and certify that each remote operator has completed training sufficient to enable him or her to safely execute the duties of a remote operator and possesses the proper class of license for the type of test vehicle being operated. The manufacturer is required to provide the DMV with a course outline and description of the remote operator training program and the date that each remote operator completed the program.

Registration and Titling

It is required for an autonomous vehicle to identify the vehicle as autonomous on registration card and on the certificate of ownership.

Application Fees

The application for testing requires a fee of $3,600 for the processing of the application that will accommodate up to 10 driverless autonomous test vehicles. Additional fee of $50 is required for each set of 1 to 10 vehicles. For the application of full deployment, a fee of $3,275 for the processing of the application is required.

Connecticut

Connecticut enacted legislation in 2017, "An Act Concerning Automated Driving System Equipped Vehicles", which, besides defining key AV related terms, allowed the testing of AVs with automation level 4 or 5 under certain conditions including the presence of an operator [22]. However, a pilot program must be developed, and testing is allowed only in four municipalities in the state, which are to be designated by the Connecticut DOT Commissioner. The 2017 legislation also establishes a task force to study AVs.

Testing

Testing AVs was the focus of the enacted bill, Senate Bill 17-260, where it mandates the presence of human driver to conduct the pilot testing.

Insurance

Proof of liability insurance, self-insurance or a surety bond of at least $5 million should be provided to conduct testing on Connecticut highways.

Safety

The AV testing could be prohibited by the state secretary, in consultation with the Commissioners of Motor Vehicles, Transportation and Emergency Services and Public Protection, if it poses risk to public safety.

Colorado

In 2017, the state of Colorado enacted a law to authorize the use of AVs under certain conditions. The bill, Senate Bill 17-213, included definitions and general declarations [23]. The legislation authorized the use of SAE levels 0-3 automation with human driver and SAE levels 4-5 automation with or without human drivers as long as they can comply with all applicable state and federal laws. In order to examine the impacts of new and emerging technologies and transportation business models, Colorado enacted another law, Senate Bill 19-239, related to AVs in 2019 [24]. The law requires the Colorado Department of Transportation (CDOT) to convene a stakeholder group comprising of representatives from AV manufacturers and technology companies.

District of Columbia

In 2012, the District of Columbia enacted legislation, B19-0931, authorized the operation of AVs with a backup human driver and be capable of following the district's traffic laws [25]. However, an amendment, B23-0232, was enacted in 2020 that established an AV testing program to be administered by the District's Department of Transportation. Furthermore, the amended legislation now authorized the District's Department of Transportation to issue permits, restrict testing under certain conditions, to establish operational standards for AVs, to require an AV testing entity to report certain data and crash information, and to require the District's Department of Transportation to provide a report with recommendations and a timeline to safely accommodate the full deployment of autonomous vehicles.

Testing

The 2020 Amendment to the act was mainly issued to regulate the testing of the AVs [26]. It stated that the testing must be conducted with either a human operator/driver inside the AV or a remote operator. As part of its application, an AV testing entity is required to submit the name, address, contact information for a point-of-contact, vehicle information and the following to the Department for approval:

- A safety and risk mitigation assessment
- A description of the operational design domain in which an AV testing entity intends to test, including the circumstances under which testing would occur with a remote operator, if applicable.

- Certification of compliance with all applicable FMVSS, including reference to an applicable exemption granted by the National Highway Traffic Safety Administration, if any.
- Certification of compliance with the applicable traffic and motor vehicle laws of the district.
- Capable of achieving minimal risk condition in case of a failure when the test operator is not inside the vehicle and if the test operator is present inside the vehicle, alert the test operator to take over manual control.

Insurance

An instrument of insurance issued by an insurer admitted to issue insurance in the district; or a surety bond issued by an admitted surety insurer or an eligible surplus lines insurer, and not a deposit in lieu of bond; or a certificate of self-insurance with an amount of $5 million should be provided.

Safety Reports

The AV applicant should provide its most recent Voluntary Safety Self-Assessment as established by NHTSA or a comparable safety and risk mitigation plan. This plan should include the intended operational design domain for testing, the disengagement technology that complies with the industry standards, and the safety operator training program.

Operators

The testing is only allowed if either a test operator is present inside the vehicle or a remoter operator is monitoring the AV. Per D.C. Law 23-156, Autonomous Vehicles Testing Program Amendment Act of 2020, the AV testing is required to "create a test operator training program that meets minimum requirements as set by the Department or is reasonably equivalent thereto and each test operator or remote operator shall successfully complete the training program before testing with an associated autonomous vehicle in the District".

Crash Reporting

The AV is required to be equipped with a mechanism to capture and store sensor data from the relevant period preceding a crash between the vehicle and another vehicle, object, or person while the vehicle is under autonomous operation.

The AV provider should notify the District's Department of Transportation of the occurrence of any crashes. The reporting should include the name of the safety operator involved in the accident; the approximate date, time, and location of the accident; the severity of the accident, to the extent known; and the name and title of the autonomous driving provider representative reporting the accident.

Registration and Titling

An AV testing entity is required to submit an inventory list to the District's Department of Transportation on a quarterly basis that includes the relevant registration information, such as vehicle tag number and state of issuance, vehicle information number, vehicle make, model, and year, and proof of current vehicle registration.

The District's Department of Transportation shall issue a testing permit to the AV tester, which is valid for one year and can be renewed annually.

Tax/fees

The District's Department of Transportation can set the term for which an AV testing permit lasts before requiring renewal and the fees associated with testing an autonomous vehicle in the district.

Delaware

In 2017, the Governor of Delaware issued an executive order establishing an Advisory Council on Connected and Autonomous Vehicles [27]. The Advisory Council was tasked with recommending innovative tools and strategies to prepare Delaware's transportation network for connected and autonomous vehicles. The Advisory Council is tasked with developing recommendations based on the following four subject areas for innovative tools and strategies that can be used to prepare Delaware's transportation network for connected and autonomous vehicles:

- Promoting economic development.
- Technology, security, and privacy.
- Transportation network infrastructure.
- Impacts on public and highway safety.

Florida

In 2012, Florida authorized the operation of AVs in the state roadways for testing purposes only under conditions set forth in legislation, HB 1207, including the presence of a human operator in the vehicle [28]. However, 2016 legislation modified the requirements and authorized full operation of AVs in the state and also relaxed the requirement for a human operator presence inside the vehicle. In 2019, the state removed the requirements for the operator to possess driver license for fully autonomous operation, defined "On-Demand Autonomous Vehicle Network", and established insurance requirements for AVs for personal use. The particular details of the regulations set forth in Florida are as follows.

Full Deployment

A fully autonomous vehicle is allowed to operate in the State of Florida regardless of whether a human operator is physically present in the vehicle as long as the following conditions are met:

- Compliance with applicable FMVSS; bear the required certification label or labels (49 C.F.R. part 567) including reference to any exemption granted under applicable federal law.

- Compliance with the applicable traffic and motor vehicle laws of this state, regardless of whether the vehicle is operating with the automated driving system engaged.
- If the autonomous vehicle is not fully autonomous, the vehicle must have a system to safely alert a licensed human operator physically present in the vehicle.
- If the autonomous vehicle is fully autonomous, it must be capable of initiating minimal risk condition in case of vehicle failure.

Teleoperation System

An autonomous vehicle or a fully autonomous vehicle equipped with a teleoperation system is also allowed to operate without a human operator physically present in the vehicle when the teleoperation system is engaged. Such vehicle must meet the requirements set forth for the full deployment of autonomous vehicles.

Insurance

The regulations in Florida require the on-demand autonomous vehicle network, owner, or registrant of a fully autonomous vehicle to carry a primary liability coverage for death, bodily injury, and property damage in the amount of $1 million. For other types of coverage such as personal injury protection benefits and uninsured and underinsured vehicle coverage, existing state laws are applicable.

Crash Reporting

In the event of a crash, it is required for the vehicle owner, or a person on behalf of the vehicle owner, to promptly contact a law enforcement agency to report the crash or the requirement is satisfied if the fully autonomous vehicle has the capability of alerting a law enforcement agency to the crash.

Driver/Operator Licensing

If the autonomous vehicle is not fully autonomous, the vehicle is required to have a system to safely alert a licensed human operator physically present in the vehicle.

Truck Platooning

The truck platooning legislation enacted in 2016, HB7061, defined autonomous technology and driver-assistive truck platooning technology [29]. The legislation required a study on the use and safe operation of driver-assistive truck platooning technology. A pilot project was initiated upon the conclusion of the study and the operation of truck platooning in the state is being carried out under the pilot project.

Georgia

The State of Georgia has enacted the Autonomous Vehicle State Bill Tracking Database authorizing and defining automated driving systems and few other key terms related to AVs and vehicle platooning in 2017 [30].

Full Deployment

The operation of a fully autonomous vehicle with the automated driving system engaged without a human driver being present in the vehicle is allowed, provided the following conditions are met:

- Compliance with the state's legislation on "Uniform Rules of the Road"
- Certified by the manufacturer as being in compliance with applicable FMVSS at the time of its manufacture.
- Capable of meeting the requirements of the state's Code section pertaining to accidents.
- Ability to initiate minimal risk condition in case of vehicle failure.

- Meet the insurance requirements set forth in the legislation, HB472.

Insurance

The legislation requires that until December 31, 2019, the AVs operating in the state are required to have minimum liability coverage in the amount of 250 percent of what is required under existing state insurance laws. Consequently, on and after January 1, 2020, the existing state insurance laws are applicable.

Crash Reporting

When a crash occurs involving a fully autonomous vehicle with the automated driving system engaged, the requirements of the state's Code subsection pertaining to accidents is considered satisfied if the fully autonomous vehicle remains on the scene of the crash as required by law and the fully autonomous vehicle or operator promptly contacts a local law enforcement agency and communicates the information required by the relevant chapter of the state's Code.

Registration and Titling

It is required in the legislation, HB472, that the AV be registered in accordance with the state's Code section pertaining to registration and license requirements and identified on such registration as a fully autonomous vehicle or lawfully registered outside of this state.

Vehicle Platooning

The Following Too Closely citation was enacted in 2017 and it added a new subsection to the existing Official Code of Georgia (Code Section 40-6-49) and it states in pertinent part:

> … the term "coordinated platoon" means a group of motor vehicles traveling in the same lane utilizing vehicle-to-vehicle communication technology to automatically coordinate the movement of such vehicles.

Hawaii

Much of the AV related research in the State of Hawaii is conducted by the dedicated research lab at the University of Hawaii. However, there has not been widespread testing or deployment of driverless vehicles in the state. The Governor of Hawaii signed Executive Order 17-07, in 2017 directing several state departments to work with any companies wishing to test autonomous vehicles in Hawaii. A 2019 legislation, HB2591, was adopted in which the Attorney General was requested to convene an AV legal preparation task force to prepare Hawaii for the legal and regulatory implications of transitioning to AVs. Recently, in 2020 the Governor signed Act 021 which turns the AV testing program bill, "Relating to Autonomous Vehicles", into law [31]. The 2020 legislation authorizes the testing of AVs on any public road in the state until at least 2023 with the presence of a human driver inside the vehicle.

The State of Hawaii provided very generic legislation that does not include detailed regulations for testing and/or operation of AVs and platoons. The 2020 enacted legislation authorized only testing of AVs with the presence of human operator with the vehicle.

Idaho

Idaho is one of the states yet to enact a law regarding the testing or deployment of AVs on Idaho roadways. However, in 2018 an executive order was issued to create an autonomous and connected vehicle testing and deployment committee. The missions of the committee included identification of all agencies with relevant jurisdictions to AV testing and deployment, facilitating coordination among those agencies, review of existing legislations, and identification of relevant state strategies.

Illinois

Illinois has no legislation directly regulating AVs, however a 2017 legislation, HB 791, prevented local authorities from banning AVs [32]. Executive Order 2018-13 signed by Governor Bruce Rauner, issued in 2018, allows the operation of AVs in the state with the presence of an employee of the manufacturer behind the wheel and all testing must be approved by the state DOT.

Indiana

Indiana currently has no laws regularizing AV testing in the state. However, a 2018 legislation, HB1290, defined vehicle platooning and exempted vehicle with electronic coordination from following-too-close provisions of 300 feet [33].

Vehicle Platooning

Indiana's HB1290 addresses vehicle platooning by defining it as the coordinated movement of multiple vehicles using electronic systems. This legislation exempts electronically coordinated vehicles in a platoon from the state's 300-foot "following-too-close" rule, allowing them to follow one another more closely while maintaining safe operation. This adjustment is aimed at enhancing traffic efficiency and safety by leveraging technology for coordinated driving.

Iowa

Iowa DOT formed an Advisory Committee on Automated Transportation that are tasked with providing guidance, recommendations, and strategic directions related to AVs in the state. The Autonomous Vehicles | Self-Driving Vehicles Enacted SF302, in 2019, and it defined key terms related to AVs and authorized the operation of AVs [28].

Full Deployment

The operation of a driverless-capable vehicle or an on-demand driverless-capable vehicle network is allowed to operate on the public highways of the state without a conventional human driver physically present in the vehicle, if the vehicle meets all of the following conditions:

- Capable of initiating minimal risk condition in case of a vehicle failure.

- Compliance with the applicable traffic and motor vehicle safety laws and regulations of this state
- Certified by the vehicle's manufacturer to be in compliance with all applicable FMVSS.

Licensing

If the motor vehicle equipped with an automated driving system, capable of performing the entire dynamic driving task within the automated driving system's ODD on the public highways of the state, is being operated with a human driver, then the human driver is required to possess a valid driver's license.

Kentucky

Kentucky only has 2018 legislation, SB116, regulating truck platooning. However, no information about testing and operation of AVs was provided [34].

Truck Platooning

The legislation allowed the operation of commercial vehicles only in platoons provided the motor carriers notify the Kentucky Transportation Cabinet and the Kentucky State Police, and must include a plan for general platoon operations. Furthermore, the presence of an appropriately endorsed driver with a valid commercial driver's license is required behind the wheel of each commercial motor vehicle in a platoon. The commercial vehicles involved in a platoon, for the purpose of warning other motorists and law enforcement, are also required to display a marking of being involved in a platoon.

Louisiana

Louisiana has enacted two laws authorizing the operation of autonomous commercial motor vehicles and platoons.

Full Deployment

It is mentioned in the bills, HB308 and HB455, that the autonomous commercial motor vehicles are authorized to operate within the state without a human operator being presented in the vehicle given the following conditions are met:

- Compliance with applicable Federal law, and the traffic and motor vehicle laws of this state, including but not limited to applicable laws concerning the capability to safely navigate and negotiate railroad crossings is mandatory for all autonomous vehicles and operators, ensuring safe and legal operation in various driving environments and scenarios.
- Properly registered and titled in accordance with applicable state laws.
- Certification of compliance with FMVSS and bears the required certification label or labels (49 CFR Part 567).
- Capable of achieving a minimal risk condition if a failure occurs.
- Fulfill the insurance requirements.

Insurance

Proof of motor vehicle liability coverage in the amount of $2 million is required.

Licensing

Autonomous commercial vehicles equipped with a teleoperation system is also authorized under the legislation and the remote driver is considered to be the operator of the vehicle for the purpose of assessing compliance with applicable traffic or motor vehicle laws including the rules of the road. The remote driver is required to hold the proper class of license for a conventional driver to operate the vehicle.

Crash Reporting

The operator or any person on behalf of the operator of the autonomous commercial motor vehicle is required to report the crash to the appropriate law enforcement agency.

Platooning

The platoon operator shall provide an operation plan prior to conduct any platoons. Additionally, the operation of platoons is not allowed on two-lane highways.

Maine

The Maine Highly Automated Vehicles (HAVs) Advisory Committee was created as directed in Executive Order, EO2018-001, issued, in 2018. The aim of this committee was to oversee the introduction of AVs and assess, develop, and implement recommendations for pilot projects that advance these technologies. The order also required interested companies to contact the committee asking for permits to test, and operate AVs on public roadways in Maine. Later in the same year, HP1204, was enacted establishing the Advisory Commission on AVs to coordinate efforts among state agencies and knowledgeable stakeholders for the purpose of developing a process for testing AVs on Maine's public roadway. Under HP1204, the Commission on AV was required to establish rules and processes to evaluate and authorize AV testing, and was granted authority to prohibit testing if it risks public safety or fails to comply with requirements. Due to some legislative challenges, such as a pending bill to prohibit the operation of driverless commercial vehicles, Maine remains behind other states in terms of AV testing on public roadways.

Maryland

The state has no laws governing the operation of AVs. However, in 2015, a CAV working group was established for the development and deployment of emerging CAV technologies in

Maryland. In 2017, the Maryland Department of Transportation (MDOT) has introduced a permit process where an entity with plans to test HAVs in Maryland has to go though.

Testing

A manufacturer is required to obtain a permit if the testing is intended to be done on open public roadways. Conversely, a permit is not required for testing on closed roadways. In the application for the permit, the following are required:

- Test operator information (driver's license number, and jurisdiction licensed in).
- Vehicle information (VIN/serial number, vehicle type, year, make, model).
- Agreement of the test operator's compliance with traffic rules of the road.
- Certification of compliance with FMVSS or equivalent; or proof of exemption by NHTSA.
- Self-certifications of operator training, proper testing of the technology.

Insurance

Manufacturers are required to provide evidence of the ability to satisfy a judgment or judgments for damages for personal injury, death, or property damage caused by a vehicle in testing in the form of an instrument of insurance, a surety bond, or proof of self-insurance, for no less than $5 million.

Safety Reports

If a Safety Assessment Letter (SAL) is submitted to the NHTSA, then either a copy of the SAL is required or a safety and compliance plan must be submitted to MDOT.

Crash Liability

The manufacturer or other entity permitted to test HAVs is the liable party for any of their vehicles and drivers/operators of their vehicles.

Massachusetts

Massachusetts got the wheels rolling on AV testing and deployment through Executive Order No. 572, issued in October 2016 and thereby creating a working group. The executive order designated the Massachusetts Department of Transportation (MassDOT) as the lead agency in creating a process to allow the testing of AVs on public roads in the Commonwealth. The application package that needs to be submitted to and approved by the MassDOT must include: the application to test, testing plan, and memorandum of agreement (MOA).

Testing

The application package should be submitted with documentation of prior testing experience, a safety assessment, training, and operations protocols, and a first responder interaction plan. Furthermore, certain information for drivers, vehicles, and proof of insurance are also required.

MassDOT has set forth the roads that are available for testing. It must be indicated in the application where within the testing plan such activities are anticipated to occur within the approval period (at most two years).

The MOA should include definitions, the application and approval process, and the terms and conditions for testing, the outlines crash protocols, the reporting requirements, the terms of approval, and any additional details for testing.

Insurance

MOA should include that commercial general liability for bodily injury and property damage should be carried in the amount of $1 million per occurrence, and $2 million annual aggregate. Furthermore, the MOU must require automobile liability covering all owned, non-owned, hired, leased, rented vehicles and test vehicles with limits no less than $1 million combined single limit. Excess coverage (Umbrella Liability) needs to be provided over the general liability, products liability, if not included in the general liability, automobile liability, and employer's liability coverages are subject to a minimum limit of $5 million per occurrence and in the aggregate.

Safety Reports

The AV testers are required to submit a progress report detailing the test activities and any disengagements, at least quarterly to MassDOT, which will be posted online for public consumption testing plan and activities.

Crash Reporting

A Crash Response Form must be submitted within 10 business days following the submission of a crash report, as described in the MOA. - Crash Protocol section.

Driver/Operator Licensing

Each test driver and safety associate (an employee other than the driver present in the vehicle) is required to possess a valid driver's license issued by a state or territory of the U.S.

Michigan

The Michigan CAV technology strategic plan was developed in 2013 to integrate recent advances in technology and policy regarding CAVs into Michigan Department of Transportation (MDOT) long-term plans [35]. Permission to test AVs on Michigan roadways under certain conditions also came in 2013 through Senate Bill 169, which defined key terms related to AVs and addressed the liability of the vehicle manufacturer [36]. To further regularize the AV testing and deployment in the state, Michigan enacted four bills (S995, S996, S997, and S998) in 2016 which provide the following regulations.

Full Deployment

An automated motor vehicle is allowed to be operated on a street or highway in this state. When engaged, an automated driving system is allowed for operation without a human operator and the automated driving system is considered the driver or operator of a vehicle for purposes of determining conformance to any applicable traffic or motor vehicle laws and be deemed to satisfy electronically all physical acts required by a driver or operator of the vehicle.

Vehicle Platooning

The operation of a platoon on a street or highway of the state is allowed if a plan for general platoon operations is filed with the department of state police and the state transportation department before starting platoon operations.

Minnesota

Minnesota has no laws or regulations specifically addressing autonomous vehicles. In 2019, Minnesota Department of Transportation (MnDOT) formed an advisory council through an executive order with the aim to study, assess, and prepare for the opportunities and challenges associated with the adoption of AVs and related technologies. One of the key strategies suggested by the council includes a recommendation regarding state laws and administrative rules update. The advisory council implemented two bills to authorize AV testing and truck platooning out of which truck platooning legislation was enacted in 2019. According to the legislation, platooning is only allowed on specific state highways.

Vehicle Platooning

To operate a platoon, one needs to submit a plan to the commissioner of MnDot to use a platooning system on freeways and expressways and get approved. The plan must include information pertaining to total length of the vehicle platoon; the configuration of the vehicle platoon, including spacing between vehicles; proposed route and section of freeway or expressway; proposed time frames the vehicle platoon will be operating; certification that each human driver in the vehicle platoon has a valid driver's license for the type or class of vehicle being driven; certification that the vehicle height, width, and weight limits conform to the requirements of the legislation; and vehicle identification information. Furthermore, the vehicle platoons must meet the following requirements:

- The platoon must not include more than three vehicles.
- Each vehicle in the vehicle platoon must have a platooning system installed and engaged while platooning.
- Each vehicle in the platoon must be covered by minimum liability insurance.
- Each vehicle in the platoon must have a paper or electronic copy of the approved plan in the vehicle.

Mississippi

The state has laws regularizing truck platoons only.

Vehicle Platooning

The laws provided safe regulations regarding the appropriate following distances for vehicles operating on highways. However, it excluded the platooned vehicles from the provided regulations as long as the platoon is operating on a limited access divided highway with more than one lane in each direction. The number maximum number of platooned vehicles is two vehicles in the platoon. An operation plan for the platoon should be approved by the Mississippi Department of Transportation and the Mississippi Department of Public Safety prior to deployment.

Nebraska

Legislation Bill 989, enacted in 2018 allowed the operation of AVs without a human driver in the vehicle and on-demand AV networks to transport people and goods under conditions set forth in the legislation [37].

Full Deployment

The operation of a driverless-capable vehicle or on-demand driverless-capable vehicle network is allowed on the public roads of the state without a conventional human driver physically present in the vehicle, as long as the vehicle meets the following conditions:

- Capable of initiating minimal risk condition in case of a vehicle failure.
- Compliance with the applicable traffic and motor vehicle safety laws and regulations of the state.

Crash Reporting

In the event of a crash, the automated-driving-system-equipped vehicle is required to remain on the scene of the crash and the owner of the automated-driving-system-equipped vehicle, if capable, or a person on behalf of the automated-driving-system-equipped vehicle owner, is required to report the crash.

Licensing

If the motor vehicle equipped with an automated driving system capable of performing the entire dynamic driving task within the automated driving system's ODD on the public highways of the state, is being operated with a human driver, then the human driver is required to possess a valid driver's license and capable of regaining manual control of the vehicle upon initiation of TOC from the automated driving system.

Nevada

In 2011, Nevada was the first state to authorize the operation of AVs and a driver's license endorsement for AV operators by enacting a law, Assembly Bill 511, [28]. Also, in 2011 the State of Nevada permitted the use of cellphones or other handheld wireless devices in a legally operating AV while prohibiting the use of such devices in a driver operated vehicle. In the following years, the State of Nevada enacted two more laws related to AVs. The law in 2013 requires that AVs meet certain conditions for being tested on highways. However, the 2017 legislation included testing or operation in the regulations of AVs.

Testing or Operation

A fully autonomous vehicle is allowed to be tested or operated on a highway within this state with the automated driving system engaged and without a human operator if the fully autonomous vehicle is capable of achieving a minimal risk condition if a failure of the automated driving system occurs which renders the automated driving system unable to perform the dynamic driving task relevant to its intended operational design domain.

However, if the AV is not a fully autonomous vehicle, a human operator must be present inside the vehicle and the AV must be equipped with:

- a means to engage and disengage the automated driving system,
- an indicator located inside the AV which indicates when the automated driving system is operating the AV, and
- a means to alert the human operator to take manual control of the AV in case of a failure.

AVs are allowed to be tested or used on a highway within this state with a human operator if the autonomous vehicle is capable of operating in compliance with the applicable motor vehicle laws and traffic laws of this State and such a federal law or regulation.

Insurance

It is mentioned in AB69, testing AVs within the state, proof of insurance or self –insurance should be provided to the DMV in the amount of $5 million. However, for full deployment or operation the minimum insurance required is not mentioned.

AV network companies are required to provide proof of insurance in an amount of $1.5 million or more for bodily injury to or death of one or more persons and injury to or destruction of property of others in any one accident or motor vehicle crash that occurs while providing transportation services using a fully autonomous vehicle as defined in the legislation.

Crash Liability

The original manufacturer is accounted liable for crashes if the automation was provided by a third party.

Crash Reporting

For testing, the person responsible for operation should report the crash within 10 business days from the crash occurrence. The identified threshold was $750 crash worthiness to be reported.

Additionally, the AV network company shall provide to the authority reports containing information relating to motor vehicle crashes, which occurred in this state while a fully autonomous vehicle was providing transportation services within a limited time period identified in the bill.

Registration and Titling

Before operating an AV within the state, it is required that the AV should be certified to comply with the requirements provided in the bill. It is required to have a valid permit issued by the Nevada Transportation Authority to engage an autonomous vehicle network company in business.

The Nevada Transportation Authority is authorized and empowered to regulate all AV network companies who operate or wish to operate within this State.

AB69, identified a fine of $2,500 if any regulation provided in the bill was violated. Additionally, it is considered as a gross misdemeanor if any person knowingly to falsify any application regarding the AV application or licensing. Moreover, if the Nevada Transportation Authority determines that an AV network company has violated the terms of a permit, it may suspend or revoke the permit as well as imposing a fine amount which does not exceed $100,000 per violation.

Application fees

A fee amount established by the Nevada Transportation Authority is going to be charged for applicant permits to operate an AV network company in this state.

Platooning

In the 2017 legislation, the state authorized the use of driver-assistive platooning technology within the state if it is capable of complying with the motor vehicle laws and traffic laws. Regulations for spacing between vehicles is provided as a minimum of 500 feet space for trucks with a width of 80 inches should be provided. Truck platoons are excluded from this regulation.

New Hampshire

The state enacted legislation in 2019 establishing an AV advisory commission, AV testing pilot program, and providing the requirements for AV deployment [28]. The state, through the legislation, allowed the testing of AVs without a human driver in the vehicle. New Hampshire also separated regulations for testing vs. full deployment.

Full Deployment

The operation of a driverless capable vehicle or on-demand autonomous vehicle network is allowed on the public roads of this state without a conventional human driver, provided that the vehicle meets the following conditions:

- Capable of initiating minimal risk condition in case of a vehicle failure.
- Compliance with all applicable traffic and motor vehicle safety laws and regulations of this state.
- Compliance with all federal laws and regulations or has an exemption under federal law.
- Proof of financial responsibility satisfactory to the department that satisfies the requirements of the existing state laws for all motor vehicles.

Testing

The testing of an ADS-equipped vehicle on public roadways of this state by a testing entity is allowed only if the testing entity has been approved for testing by the department after submitting the following information: name and business address of the entity; contact information of the lead staff; vehicle identification (make, model, license plate number); description of ODD with limitations; geographic locations of testing; either Voluntary Safety Self-Assessment or summary of safety training of the test drivers; proof of insurance; and acknowledgement of:

- All applicable federal laws and regulations.
- All traffic and motor vehicle safety laws and regulations of this state.
- Testing in controlled conditions and demonstration of functionality ready to test on public roads.
- Operated or monitored by trained employees, or other authorized persons as agents of the testing entity who have received instruction on the safe operation of vehicle systems.
- Test driver holding a valid driver's license.

A testing entity in the automated vehicle testing pilot program is allowed to operate an ADS-equipped vehicle without a test driver or conventional human driver in the vehicle, provided that the testing entity submits an application to the department of its intention to proceed with such testing. Such application is required to include:

- Acknowledgment by the testing entity of the vehicle’s capability of initiating minimal risk condition.
- Emergency response guide.

Insurance

For testing, the minimum liability coverage is set at $5 million and for full deployment the existing state insurance laws for all motor vehicles are applicable.

Safety Reports

The following safety reports or emergency guide are required for testing in the state:

- A copy of the testing entity's Voluntary Safety Self-Assessment as defined by the USDOT Federal Automated Vehicles Policy or a detailed summary of the types of safety training given to test drivers, including copies of any documentation or illustration is required.
- A copy of the testing entity's emergency response guide, including information on how to instruct law enforcement, fire, and emergency medical personnel on safe interaction with the vehicle in emergency and traffic enforcement situations and distribute to all law enforcement, fire, and emergency response personnel with jurisdiction over the geographic area in the vicinity of the test entity's stated testing area.

Crash Liability

If a vehicle under driverless operation fails to remain at the scene of an accident or the operation of the vehicle fails to otherwise comply with the applicable state laws, the vehicle's failure is imputed to the vehicle's owner, and the vehicle's owner may be charged and convicted of a violation of the state laws as applicable. However, if the vehicle's failure is due to an error or malfunction in the automated driving system, the vehicle's failure is imputed to the vehicle's manufacturer, and the vehicle's manufacturer may be charged and convicted for a violation of state laws as applicable.

Crash Reporting

The vehicle's owner or a person on behalf of the vehicle's owner is required to promptly report the accident to law enforcement authorities.

Licensing

For testing with drivers, the ADS-equipped vehicle test driver is required to hold a valid driver's license that is recognized by the state as affording the individual the privilege of legally operating a motor vehicle on state roadways.

Application Fees

For testing, an annual fee of $500 is collected from each testing entity participating in the automated vehicle testing pilot program.

New Jersey

The New Jersey Advanced Autonomous Vehicle Task Force was established through a law enacted in 2019 with the purpose of conducting a study of advanced autonomous vehicles and to make recommendations on laws, rules, and regulations that this State may enact to safely integrate advanced autonomous vehicles on the State's highways, streets, and roads.

New York

Only testing or demonstration of AVs is allowed in New York by manufactures or entities involved in developing such technology, under the legislations enacted in 2017, Senate Bill S2005C, and Assembly Bill A3005C, enacted in 2018, provided the approval from the commissioner of the state DMV is obtained. Furthermore, Assembly Bill A3005C also require the testing to be carried out under the supervision of the state police and in a form and manner prescribed by the superintendent of the state police. The legislation and regulations in New York make it one of the most restrictive states for AV testing [38]. The state DMV provides details of the regulations in their website and the required forms that the AV testers need to fill out for initiating testing/demonstration of AVs in the state.

Testing

The enacted bills allow testing of AVs within the state highways with a human operator to monitor the vehicle's performance and resume full control of the AV if necessary. Additionally, the AV must comply with all federal standards and applicable New York State inspection standards.

Insurance

To conduct testing of AVs, the entity is required to submit an instrument of insurance, surety bond or proof of self-insurance acceptable to the commissioner in the amount not less than $5 million.

Safety Reports

AV testers in the state are required submit their report on demonstrations or tests, undertaken pursuant to a DMV permit, to the Commissioner of Motor Vehicles. Also, a law enforcement interaction plan must be submitted.

Driver/Operator Licensing

The AV being tested is required to have a licensed driver behind the wheel and requires that every test vehicle operator be adequately trained in the safe operation of the test vehicle to ensure both legal and safe operation.

North Carolina

AVs in the state are permitted to operate under the legislation enacted in 2017, HB469, as long as they are covered by insurance and meet existing state and Federal laws [28]. The legislation also established the Fully Autonomous Vehicle Committee.

Full Deployment

The operation of a fully autonomous vehicle is allowed if the vehicle meets all of the following requirements:

- Capable of being operated in compliance with all applicable state laws.
- Compliance with applicable Federal law and regulations
- Compliance with applicable FMVSS and bears the required certification label or labels (49 C.F.R. Part 567).
- Capable of initiating minimal risk condition in case of vehicle failure.

Crash Reporting

In the event of a crash the vehicle or the operator of the vehicle is required to promptly contact the appropriate law enforcement agency to report the crash. The vehicle or operator of the vehicle is also required to promptly call for medical assistance, if appropriate. For a reportable crash, the vehicle needs to remain at the scene of the crash until vehicle registration and insurance information is provided to the parties affected by the crash and a law enforcement officer authorizes the vehicle to be removed. For a nonreportable crash, the vehicle needs to remain at the scene or in the immediate vicinity of the crash until vehicle registration and insurance information is provided to the parties affected by the crash.

Registration and Titling

The vehicle is required to be registered in accordance with state laws, and, if registered in this state, the vehicle is required to be identified on the registration and registration card as a fully autonomous vehicle.

Licensing

The operator of a fully autonomous vehicle with the automated driving system engaged is not required to be licensed to operate a motor vehicle.

Truck Platooning

Existing state laws prohibit the driver of a motor vehicle from following another vehicle more closely than is reasonable and prudent, having due regard for the speed of such vehicles and the traffic upon and the condition of the highway. Also, the driver of any motor vehicle traveling upon a highway outside of a business or residential district and following another motor vehicle is required to, whenever conditions permit, leave sufficient space so that an overtaking vehicle may enter and occupy such space without danger, except that this does not prevent a motor vehicle from overtaking and passing another motor vehicle. The legislation enacted in 2017, HB716, added a subsection to the existing following too closely legislations that exempts the driver of any non-leading commercial motor vehicle traveling in a platoon on any roadway where the Department of Transportation has by traffic ordinance authorized travel by platoon from any such regulations.

North Dakota

A law enacted in 2015, HB 1065, by the state of North Dakota provides for a study to revise current laws to accommodate the introduction or testing of AVs in North Dakota and research into the degree that AVs can improve traffic safety [28]. A revision to the 2015 Act was enacted in 2017 that provided for AV related study and facilitated collaboration between North Dakota

DOT (NDDOT) and the AV technology industry [39]. Recently, two more laws were enacted that updated the AV related definitions, such as platoons, and clarified laws pertinent to AV operation.

Full Deployment

The operation of an AV with automated driving systems engaged or an on-demand AV network is allowed to operate without a human driver on the public highways given the following conditions are met:

- Compliance with all applicable federal and state law.
- Capable of achieving a minimal risk condition.

Licensing

If the person using an AV is not driving or in actual physical control of the AV, then the person is exempt from licensing requirements provided that the automated driving system is completing the entire dynamic driving task and capable of achieving minimal risk condition.

Vehicle Platooning

Existing state laws prohibit the driver of a motor vehicle from following vehicle more closely than is reasonable and prudent, having due regard for the speed of such vehicles and the traffic upon and the condition of the highway. The vehicle platooning legislation enacted in 2019, HB1199, prevented the following too closely regulations from being applicable to the operation of a non-lead vehicle in a platoon. Furthermore, the legislation also requires that the platooning technology provider or the commercial motor vehicle operator to file an operational plan with the department and the plan requires approval for general platoon operations.

Under HB1199, the NDDOT, in coordination with the state highway patrol superintendent, is required to develop an operational plan that provides guidelines for operating a platoon. The plan must include operational information that must be provided by a platoon technology provider or commercial motor vehicle operator. The department may restrict platooning operations in accordance with the guidelines or the operational information provided in the plan.

Ohio

The AV related initiatives in Ohio were mobilized through multiple executive orders issued in 2018. Firstly, the DriveOhio initiative was created within the Ohio DOT (ODOT) to facilitate collaboration between researchers, developers, and manufacturers [40].The second executive order authorized the testing of AVs on an Ohio public roadway given that the entity willing to initiate AV testing in Ohio follow certain rules and conditions.

Testing

A company is required to inform DriveOhio of the routes or areas where the company intends to perform testing without an operator in the vehicle and the designated operators that will be monitoring each vehicle. Additionally, where testing without an operator in the vehicle occurs within the jurisdiction and authority of a municipality, the company and DriveOhio will coordinate on providing notification to relevant municipalities where the company will perform such testing.

The testing and pilot programs for autonomous vehicles are authorized on any public road or highway in the state, given that the companies to test AVs on Ohio roadways first register with DriveOhio and provides DriveOhio with all the following general information:

- The name and business address of the company
- Identification information about the vehicle(s) (make(s), model(s), and license plate number(s))
- The name(s) and contact information of any designated operator(s).
- Proof of the company's motor vehicle insurance or other financial responsibility.

- The municipalities or other areas of the state where the company plans to test an autonomous vehicle.
- The conditions under which the AV can operate in fully autonomous mode, including any restrictions under which the autonomous vehicle cannot operate.
- Certification of compliance with all applicable FMVSS or with the Federal Motor Carrier Safety Administration regulations and capability of complying with all state traffic and safety laws.

In addition to registering with DriveOhio and providing all of the general information above, before beginning testing in Ohio of a level 4 or 5 AV, each company must provide DriveOhio with assurances, in a form acceptable to DriveOhio, that their AVs will:

- Achieve minimal risk condition in case of a vehicle failure.
- Have a designated operator.
- Be capable of complying with all Ohio motor vehicle laws.
- In the event of a violation of the law or regulations of the state, or in the event of a collision, cooperate with any appropriate law enforcement agency request for information about the incident.

Operators

All AVs tested in Ohio must have a designated operator. Designated operators are not required to be inside the vehicle. Designated operator(s) must be an employee, contractor, or agent of the company testing autonomous vehicles or is faculty, staff, or a student at a college or university and is actively involved in a partnership with that entity.

Safety Reports

Prior to testing, a company is required to provide DriveOhio with a summary report outlining its approach for the safe testing of their autonomous system and how the company intends to assure public safety. Alternatively, a company may provide DriveOhio with a Voluntary Safety

Self-Assessment as established by NHTSA in the Voluntary Guidance for Automated Driving Systems, Section I.

Crash Reporting

The designated operator(s) is required to report to DriveOhio any collision originating from the operation of the AV while the autonomous technology is engaged on a public road.

Driver/Operator Licensing

The designated operator(s) is required to have a valid driver's license that is recognized by the State of Ohio.

Oklahoma

Oklahoma initiated a bill to allow testing and operation of AVs within the state. The bill mainly included definitions and providing preemption authority to test and operate AVs. Detailed regulations and rules were not provided in the bill. Another legislation in 2019 provided regulations for platoon operation but limited to two vehicles only.

Oregon

Currently, Oregon has no laws regarding the operation of AVs. However, in 2018 a law established the AV task force and clarified that the state DOT would lead the coordination of AV related programs and policies [28]. Oregon does not currently regulate AV testing, but the voluntary notification process allows ODOT to provide safety information to interested companies on work zones and lane closures on proposed test routes and dates. It also enables the department to solicit feedback from AV system developers on how to engage the industry, and to track the progress of AV testing in the state.

Pennsylvania

There are a couple of AV related laws which were enacted in 2016 and in 2018. The 2018 legislation established the Highly Automated Vehicle Advisory Committee within the state DOT and providing for AV related definitions and platooning regulations. The law is the first in the country to include a sub-section of highly automated work zone vehicles. It allows PennDOT or the Pennsylvania Turnpike Commission, as applicable, to authorize the locations in Pennsylvania on a periodic basis to implement the deployment of a highly automated work zone vehicle with a driver if such vehicle is used in an active work zone.

In 2018, the PennDOT issued a guidance on the application procedure for AV testing with a licensed driver in the driver's seat. The guidance provides regulations divided into several clear sub headers.

Testing

Pennsylvania denotes AVs as Highly Automated Vehicles (HAVs) and allows the testing of such vehicles given that a licensed driver is seated in the driver's seat with the ability to intervene in situations where the Automated Driving System (ADS) experiences a system interruption or other problem rendering the ADS unable to safely perform the dynamic driving task and the vehicle is unable to come to a minimal risk condition on its own. It is also mentioned in the guidance that under existing law, unmanned and/or remote testing on trafficways is prohibited. The HAV testers are required to submit a Notice of Testing application to the PennDOT with information pertaining to tester, vehicle, safety driver, location, and acknowledgments which includes some of the following key items:

- Compliance with all applicable Federal laws and regulations unless a proof can be provided of an exemption or waiver granted by the NHTSA for the vehicle(s), and compliance with all applicable traffic and motor vehicle laws and can obey traffic control devices within its ODD.

- Registered, titled in accordance with existing state laws, and carrying financial responsibility according to the existing state laws.
- Tester has reasonably determined that the HAV is capable of operation within the parameters of the ODD(s) by testing under controlled conditions (e.g., in simulation, closed track or on-road) for the intended ODD.
- The presence of a safety driver in the driver’s seat and the HAV must be capable of alerting the driver to take manual control, when applicable.
- Mechanism to engage and disengage the ADS that is easily accessible to the HAV safety driver, the secondary safety associate, law enforcement and other emergency responder personnel.
- Audio signal or visual display inside the cabin to indicate when the ADS is engaged.
- Equipped with data recorder to record what the HAV observed and how the HAV reacted to the information during a collision. The data should be made available to PennDOT and applicable law enforcement agencies.
- Reasonable measures, such as industry standards, best practices, company policies, or other methods, to mitigate cybersecurity risk are implemented.
- Safety drivers and secondary safety associates have successfully completed the HAV tester’s safety driver training program.
- Quality controls are deployed and monitored to ensure safe operation.

Safety Reports

The testing guidance requires that PennDOT must collect certain data from all testers on a semi-annual basis, the HAV tester is required to provide the following information to PennDOT through the Semi-Annual Data Collection Form:

- Approximate miles travelled in Pennsylvania and the number of employees involved.
- Type of roadway and counties on which HAVs were tested.

- If applicable, the approximate number of new jobs created and new facilities constructed, purchased, or rented in Pennsylvania because of HAV testing.

A Safety and Risk Mitigation Plan or alternatively A Voluntary Safety Self-Assessment as established by NHTSA in the 2017 Voluntary Guidance for Automated Driving Systems, Section I needs to be provided to PennDOT.

Crash Reporting

HAVs are required to be equipped with a means to record operational data before a collision occurs. The data shall be made available to PennDOT and applicable law enforcement agencies upon request. The tester is required to notify PennDOT's Statewide Traffic Management Center and Pennsylvania Turnpike Commission of the occurrence of any crash in Pennsylvania within 6 hours of any incident.

Vehicle Platooning

The 2018 legislation, HB 1958, included regulations for the operation of platoons such as exempting non-lead vehicles in a platoon from the following too closely regulations of the state and each vehicle must be marked with a visual identifier on the power unit. A plan for general platoon operations must be submitted to the PennDOT. If the plan is not rejected by the department within 30 days after receipt of the plan, the person may operate the platoon.

Some other regulations on the platoon operations are also provided in the legislation such as:

- The presence of a driver is required in each vehicle in a platoon.
- A maximum of three vehicles are allowed in a platoon.
- Platoons are expected to travel only on limited access highways or interstate highways, unless otherwise permitted by the PennDOT or the Pennsylvania Turnpike Commission. The PennDOT or the Pennsylvania Turnpike Commission may also restrict platoon operations due to safety or emergency reasons.

South Carolina

The state has no law regularizing the operation of AVs. In 2017 the state revised the provisions of the distance maintained between vehicles for commercial vehicles in a platoon with automated technologies.

Tennessee

Tennessee, through Senate Bill 598, which was enacted in 2015, prohibited municipal governments from banning AVs [28]. In the following year, another legislation was enacted which allowed the use of vehicles equipped with AV technology and also allowed the operator to use and interact with the integrated electronic display [41]. In a separate legislation enacted in 2016, Senate Bill 1561, the definitions of AV related operation such as autonomous technology, driving mode, and dynamic driving task were redefined [28]. The Automated Vehicles Act was also enacted in 2017 that included some key AV related regulations which are summarized as below.

Operations

An ADS-operated vehicle is allowed to drive or operate on streets and highways in Tennessee with the ADS engaged without a human driver physically present in the vehicle if the vehicle meets the following conditions:

- Capable of being operated in compliance with applicable state laws.
- Certified by the manufacturer as being in compliance with applicable FMVSS.
- Registration according to the regulations in the legislation.
- Provide proof of insurance according to the regulations in the legislation.

Insurance

Until July 1, 2021, vehicles are required to be covered by primary automobile liability insurance of at least $5million per incident for death, bodily injury, and property damage. For insurance requirements after July 1, 2021, the commissioners of safety and commerce and insurance are required to submit a joint report to the transportation and safety committee of the senate and the transportation committee of the house of representatives, making recommendations, including the appropriate rationale and any proposed legislation, on whether the insurance and bonding coverages and coverage amount requirements should be increased, decreased, extended, or otherwise amended. The report is required to be submitted no later than February 1, 2020.

Crash Liability

When the ADS is fully engaged, operated reasonably and in compliance with manufacturer instructions and warnings, the ADS will be considered the driver or operator of the motor vehicle for purposes of determining liability of the vehicle owner or lessee for alleged personal injury, death, or property damage in an incident involving the ADS-operated vehicle and liability for non-conformance to applicable traffic or motor vehicle laws.

Registration/Titling

If registered in Tennessee, the vehicle is required to be identified on the registration as an ADS-operated vehicle.

Vehicle Platooning

The legislation enacted in 2017, SB676, authorized vehicle platooning on streets and highways as long as companies notify the Tennessee Department of Transportation and Department of Safety. The notification must include a plan for general platoon operations.

Texas

Texas is one the most AV-friendly states and attracts AV testing by creating an environment through their easy regulations set forth through SB151, enacted in 2017, which authorizes the operation of an AV without a human driver as long as it meets certain conditions.

Full Deployment

The operation of an automated motor vehicle is allowed in this state with the automated driving system engaged, regardless of whether a human operator is physically present in the vehicle with following conditions:

- Compliance with applicable traffic and motor vehicle laws of this state.
- Equipped with a recording device installed by the manufacturer.
- Compliance with applicable federal law and FMVSS.
- Registration according to the regulation in the legislation.
- Proof of insurance in the amount governed by existing state laws for all motor vehicles.

Registration/Titling

The vehicle is required to be registered and titled in accordance with the laws of this state and identified to the department as an automated motor vehicle or an automated driving system.

Driver/Operator Licensing

The legislation does not require a licensed human operator to operate a motor vehicle if an automated driving system installed on the vehicle is engaged. When an automated driving system installed on a motor vehicle is engaged, the automated driving system is considered to be licensed to operate the vehicle.

Platooning

The legislation enacted in 2017, known as Public Chapter 474, allows the use of connected braking system to maintain a certain distance between the vehicles (platooning) [42].

Utah

The State of Utah initiated CAV related activities by enacting multiple legislations starting from 2015. The 2015, Autonomous Vehicle Regulations Act and 2019 revision to this legislation defined connected vehicle and authorized the state DOT to conduct connected vehicle technology testing program, obtain, collect, utilize anonymized location data of such vehicles and finally report the results of the testing program [43], [44]. The legislation enacted in 2016 required that the Autonomous Vehicle Study to be carried out on AVs that evaluated NHTSA and AAMVA standards, determined appropriate safety features and strategies, and developed recommendations [45]. The authorization of self-driving vehicles operation came through the 2019 revision to the Autonomous Vehicle Regulations Act, which among other provisions, included definition of key terms related to AVs and requirements of an AV to be properly titled, registered, and insured under state laws [46].

Full Deployment

A motor vehicle equipped with an ADS with or without driver is allowed to operate on a highway in this state following certain conditions:

- Compliance with the applicable traffic and motor vehicle safety laws and regulations of this state unless an exemption has been granted.
- Certified as being in compliance with all applicable motor vehicle safety standards; and bears the required certification label.
- Capable of initiating minimal risk condition in case of vehicle failure.
- The motor vehicle is titled and registered according to the regulations in the legislation.

Crash Reporting

In the event of a crash involving a vehicle with the ADS engaged, the ADS-equipped vehicle shall remain on the scene of the crash when required to do so, consistent with the vehicle's ability to achieve a minimal risk condition. The owner of the ADS-equipped vehicle, or a person on behalf of the vehicle owner, is required to report any crashes or collisions consistent with the chapter in Utah’s existing law pertaining to accident responsibilities. If the owner or person on behalf of the owner is not on board the vehicle at the time of the crash, the owner is required to ensure that the following information is immediately communicated or made available to the persons involved or to a peace officer upon request: the contents of the vehicle's registration card and the name of the insurance provider for the vehicle, including the phone number of the agent or provider.

The department requires that an accident report filed include whether a vehicle equipped with an ADS was involved in the accident and whether the ADS was engaged at the time of the accident.

Driver/Operator Licensing

The ADS is considered to be responsible for the compliant operation of the vehicle and is not required to be licensed to operate the vehicle.

Vehicle Platooning

An amendment to the 2015 the Autonomous Vehicle Regulations Act was enacted in 2018to include and define connected platooning system [47]. The legislation exempts the operator of a non-lead vehicle that is part of a connected platooning system from the existing "following too closely" regulations.

Vermont

Vermont enacted Senate Bill 127, in 2017 that requiring the DOT to convene a meeting of expert stakeholders in the matter of AVs, the secretary of transportation to report to the House and Senate committees regarding the meetings and any recommendations including proposed legislation. The automated vehicle testing program was formally initiated in SB149, enacted in 2019, where key terms related to AVs were defined and authorized the Agency of Transportation to adopt rules to implement this new program enacted as a separate chapter in the legislation. The 2019 legislation also laid down the conditions under which an AV testing company would be able to operate AVs on Vermont roadways such as the requirement for the presence of a human operator inside the vehicle. The enacted Vermont bill mainly focused on testing only. Legislations for full operation and platoons was not mentioned in the bill. The traffic committee is authorized to permit testing of AVs within the Class 1 town highways. Separate approval from the committee is required if testing is to be conducted on Class 2, 3, and 4 town highways.

Testing

The enacted bill allowed testing with human operator seated in the driver's seat and capable of taking immediate manual control of the vehicle. Also, the testing is allowed provided the operator and the entity testing the AV comply with applicable standards established by the NHTSA regarding the testing of AVs or are capable of providing proof of exemptions or waivers to such standards. The traffic committee has the sole authority to provide the AV testing permit, where the geographic scope of the ODD should be mentioned in the permit.

Insurance

Proof of liability insurance, self-insurance, or a surety bond of at least $5 million should be provided prior to testing an AV.

Safety Reports

The entity testing AVs is required to submit a report to the Traffic Committee annually, until all testing ceases, summarizing results and observations related to safety, traffic operations, interaction with roadway infrastructure, comments from the public, and any other relevant matters.

Crash Reporting

The operator of the AV is accounted responsible of reporting any occurred crashes within 72 hours from the crash.

Virginia

There is active AV testing going on in Virginia, yet the state has not enacted any legislations neither issued any executive orders regularizing the operation of AVs in the state. However, a 2015 Governor's Proclamation allowed the testing of AVs on Virginia roadways under the guidance of the Virginia Tech Transportation Institute (VTTI) [48]. In response to the proclamation the Virginia Automated Corridors initiative was undertaken to facilitate research and collaboration between government agencies, OEMs, suppliers, and VTTI.

Washington

Washington Executive Order 17-02, issued in 2017, addressed AV testing, formed an interagency AV workgroup, and enabled pilot programs throughout the state [49]. The executive order included instructions for the state agencies with applicable jurisdictions to support "safe testing and operation of autonomous vehicles on Washington's public roads". For safe operation of AVs on Washington roadways the executive order specifies certain requirements for AVs with and without human drivers present in the vehicles. The 2017 executive order requires that companies aiming to test in Washington roadways provide a self-certification form to the Washington State Department of Licensing [50]. The Washington State Transportation Commission convened an executive and legislative AV workgroup based on the 2018 Substitute House Bill 2970 [51]. The workgroup functioned until December of 2023 to develop policy recommendations to address the operation of AVs on public roadways in the state [52]. Recently, a new legislation was enacted in 2020 which established minimum requirements for the testing of AVs [53].

Testing

For testing with human operators present the following conditions need to be met:

- Only a trained employee, contractor, or other person authorized by the company developing the autonomous technology can operate or monitor the vehicles.

- Vehicles must be monitored, and an operator must have the ability to direct the vehicle’s movement if assistance is required.
- Anyone operating an autonomous vehicle needs a valid U.S. driver license.
- Proof of insurance is required.

For testing without human operators present the following conditions need to be met:

- Vehicles must be equipped with an automated driving system that performs all driving tasks on a part- or full-time basis within their operational design limits. Vehicles must also be able to make it to a safe condition in the event of a system failure.
- Vehicles must comply with Washington state motor vehicle laws relevant to the vehicle’s operational design limits.
- Proof of insurance is required.

Insurance

Companies testing AVs in the state must have an umbrella liability policy of not less than $5 million per occurrence and submit the Certificate of Insurance that shows they meet this rule.

Wisconsin

Executive Order 245, issued in 2017, created a Steering Committee on Autonomous and Connected Vehicle Testing and Deployment tasked with advising the Governor on how to advance the testing/operation of AVs. The committee made several recommendations in its 2018 report that are yet to be enacted [54]. The state of Wisconsin enacted SB695, in 2018 that allowed the operation of platoons within the highways of the state. Testing and operation of AVs were not mentioned in the act or the bill. It was mentioned that safe following distance should be adopted excluding the vehicles equipped with cooperative cruise control.

Wyoming

The state Senate introduced SF0007, Autonomous Vehicles, during the 2021 Wyoming legislative session. The bill was related to the regulation of AVs in the state. The legislation included definitions and regulations regarding the full deployment of AVs. There are no separate sections for testing regulations in the Bill. However, the Bill provided that the DOT "may develop procedures and issue temporary operating permits for demonstration or testing in the state of vehicles equipped with an ADS that do not meet the other requirements of this article." The article is referring to the legislation text. Furthermore, regulations pertaining to truck platooning have also not been included in the legislation. The legislation allows the operation of on-demand autonomous vehicle network and commercial vehicles equipped with an ADS. The Bill failed to pass in the state House of Representatives.

The other regulations in the legislation are summarized as follows.

Full Deployment

The operation of a vehicle equipped with ADS without a human driver is allowed provided that the vehicle meets the following conditions:

- Capable of achieving a minimal risk condition in case of a failure.
- Compliance with all applicable traffic and motor vehicle laws and regulations of this state; compliance with all applicable FMVSS or has a USDOT or other relevant agency approved exemption from specific compliance; compliance with all applicable safety standards and performance requirements required by state and federal law.

The operation of a human driven vehicle equipped with an ADS is also allowed given that the human driver is properly licensed, appropriately responds to take over request, and the ADS is capable of compliance with all applicable traffic and motor vehicle laws of the state.

Insurance

The vehicle owners are required to submit proof of financial responsibility for primary automobile liability insurance that provides at least $1 million for death, bodily injury, and property damage. Furthermore, the insurance requirements set forth in the legislation provides that manufacturers are to maintain liability insurance in the amount of at least $5 million to insure against losses caused by the vehicle equipped with an ADS and at which the manufacturer is at fault.

Crash Reporting

In the event of a crash, the vehicle is required to remain at the scent and the vehicle owner or person acting on behalf of the owner is required to report the crash or if the vehicle has the capability of promptly alerting law enforcement or emergency services, the vehicle needs to alert law enforcement or emergency services to the crash.

Crash Liability

The legislation provides that the dispatching entity, manufacturer, or both may be found liable for any crash or violation of traffic law, to be determined by the same applicable local and state laws that determine liability for a crash or violation of a traffic law involving a vehicle with a human driver.

Licensing

During the operation of a vehicle equipped with an ADS the legislation provides that ADS is considered the driver for the purpose of assessing compliance with applicable traffic or motor vehicle laws, and the ADS is considered to be licensed to operate the vehicle if the dispatching entity has a valid class of license for the type of motor vehicle being operated.

Registration and Titling

Any vehicle equipped with an ADS is required to be properly registered and titled in accordance with the state laws and identified as such vehicle on the registration and titles. Furthermore, if a vehicle is modified later by installing an ADS the previous registration and titles should be amended to reflect the new changes and identification.

AV REGULATIONS IN OTHER STATES VS. WYOMING

The following tables provide a summary of the key items included in the legislations of some states with the most comprehensive regulations such as California, Florida, Michigan, Nevada, and New Hampshire. Furthermore, by comparing the newly introduced Wyoming legislation with the legislations from the most comprehensive states, recommendations are provided for including the items missing in the legislation. The regulations are categorized into Full Deployment (Table 1), Testing (Table 2), and Platooning (Table 3).

Table 1 Full Deployment Regulations for CAV technologies

Full Deployment Regulation	States with regulation	Wyoming Bill/Recommendations
Allows full driverless operation	California, Florida, Michigan, New Hampshire, Nevada	**Included in the Wyoming Draft Bill**
Minimum Insurance	California, Nevada ($5,000,000) Florida (For On-demand AVs: $1,000,000; Others*) Michigan*, New Hampshire*	**Included in the Wyoming Draft Bill** "Primary automobile liability insurance that provides at least one million dollars ($1,000,000.00) for death, bodily injury and property damage."
Crash reporting	California, Nevada ($750 threshold by operator)	**Included in the Wyoming Draft Bill**
Provide safety guide/reports/disengagement data, etc.	California, Nevada	**Not under consideration in the current draft bill** **Recommendation:** A certification that the manufacturer has conducted test and validation methods and is satisfied, based on the results of the tests and validations, that the vehicles are safe for deployment on public roads.
Liability for collisions assumed by owners	New Hampshire	**Not under consideration in the current draft bill** **Recommendation: "**If a vehicle under driverless operation fails to remain at the scene of an accident or the operation of the vehicle fails to otherwise comply with federal and state laws where applicable and to the extent possible as required by this section, the vehicle's failure shall be imputed to the **vehicle's owner,** and the vehicle's owner may be charged and convicted of a violation of applicable federal and state laws."
Liability for collisions assumed by manufacturers	New Hampshire	**Included in the Wyoming Draft Bill** "The dispatching entity, manufacturer, or both, of a vehicle equipped with ADS involved in a crash shall be liable if either or both are at fault for any crash, each according to the same applicable local and state laws that determine liability for a crash involving a vehicle with a human driver."

Table 2 Testing Regulations for CAV technologies

Testing regulation	States with regulation	Wyoming Bill/Recommendations
Require a permit to test: Notifying local authorities:	California, New Hampshire, Nevada, Pennsylvania California only	**Included in the Wyoming Draft Bill for full deployment.** "The department may develop procedures and issue temporary operating permits for demonstration or testing of autonomous vehicles within the state. The permits shall be issued for the purpose of testing or demonstrating the use of such vehicles, systems, or networks under actual operating conditions on the highways. The permits shall be issued under the supervision of and under conditions determined by the department." **Recommendation:** The department may develop an application procedure to allow testing of ADS-equipped vehicles on public roadways of this state after submitting the required information (e.g., name, address of the entity, contact information and license of the operator/lead staff, proof of insurance, locations/ODD for testing with limitations, compliance certifications, etc.) **Recommendation:** "The local authorities within the jurisdiction where the vehicle will be tested should be notified of the ODD of the vehicles to be tested and the testing has been coordinated with those local authorities."
Require an application fee	California ($3,600 per 10 AVs) New Hampshire ($500 from each entity)	**Not under consideration in the current draft bill**
Allows driverless testing:	California, New Hampshire, Nevada	**Included in the Wyoming Draft Bill for full deployment.**
Remote Operators	California, Ohio, Pennsylvania	**Remote operators are not currently mentioned in the Wyoming draft bill.** **Recommendation:** "All autonomous vehicles tested in the state must have a designated operator. Designated operators are not required to be inside the vehicle. Designated operator(s) must have a valid driver's license that is recognized by the state."
Financial Responsibility while Testing	[California, New Hampshire, Nevada] $5,000,000 Ohio*	**Included in the Wyoming Draft Bill for full deployment.** "Primary automobile liability insurance that provides at least one million dollars ($1,000,000.00) for death, bodily injury and property damage." **Recommendation:** "The testing entity must provide proof of the entity's financial ability to satisfy judgment for damages for personal injury or property damage of at least $5 million,

Testing regulation	States with regulation	Wyoming Bill/Recommendations
		which may be in the form of an issued insurance policy, a bond, or other financial instrument.”
Liability for collisions during testing assumed by manufacturers	California	**Included in the Wyoming Draft Bill for full deployment.** **Recommendation:** The manufacturer wanting a testing permit must certify that “to the extent that the autonomous vehicle is at-fault in any collision, the manufacturer shall assume any and all responsibility for liability associated with the operation of the vehicles on public roads.”
Specify locations for testing/Specify ODD with limitations	California, New Hampshire, Nevada	**ODD not decided in the Wyoming draft bill.** **Recommendation:** The manufacturer shall not test an AV on public roads “unless the manufacturer has tested the autonomous vehicles under controlled conditions that simulate as closely as practicable each ODD in which the manufacturer intends the vehicles to operate on public roads and the manufacturer has reasonably determined that it is safe to operate the vehicles in each ODD.” **Recommendation:** Entities can be encouraged to test in adverse weather conditions, work zones, and during road closures, provided the entity can submit a safety plan for testing in these conditions.
Crash reporting	California, New Hampshire, Ohio, Nevada	**Included in the Wyoming Draft Bill for full deployment.**
Provide safety guide/reports/disengagement data, etc.	California, New Hampshire, Ohio Pennsylvania, Nevada	**Not under consideration in the current draft bill** **Recommendation:** “Require a copy of the testing entity's emergency response guide, including information on how to instruct law enforcement, fire, and emergency medical personnel on safe interaction with the vehicle in emergency and traffic enforcement situations and distribute to all law enforcement, fire, and emergency response personnel with jurisdiction over the geographic area in the vicinity of the test entity's stated testing area.” **Recommendation:** “Prior to testing, a company must provide the department with a summary report outlining its approach for the safe testing of their autonomous system and how the company intends to assure public safety. Alternatively, a company may provide the

Testing regulation	States with regulation	Wyoming Bill/Recommendations
		department with a Voluntary Safety Self-Assessment as established by NHTSA in the Voluntary Guidance for Automated Driving Systems, Section I.”
Registration/Titling	California, New York	**Included in the Wyoming Draft Bill for full deployment.**

Table 3 Platooning Regulations

Platooning regulation	States with regulation	Wyoming Bill/Recommendations
Modification/Exemption of the gap/following-too-closely requirements:	Michigan, Nevada, Pennsylvania	**Not under consideration in the current draft bill** **Recommendation:** “The provision of “following-too-closely” regulations shall not apply to the commercial motor vehicles traveling in a platoon on any roadway where the Department of Transportation has by traffic ordinance authorized travel by platoon. For purposes of this subsection, the term "platoon" means a group of individual commercial motor vehicles traveling at close following distances in a unified manner through the use of an electronically interconnected braking system."
Allows truck platooning for testing purpose only	California (till April 1, 2023)	**Not under consideration in the current draft bill** **Recommendation:** “Controlled testing of truck platoons at shorter gaps may be authorized to: • Collect and analyze enough data for assurance that adequate safety, operations, and environmental testing has been performed. • Understand lane changing behavior and how other vehicles interact with platooning trucks. • Determine the implications of cut-ins at various gap settings. • Incorporate input from commercial vehicle drivers and fleets into the cooperative adaptive cruise control design.”
Require a permit to operate platoons	Michigan North Dakota Pennsylvania	**Not under consideration in the current draft bill** **Recommendation:** “A person may operate a platoon on a street or highway of this state if the person files a plan for general platoon operations with the department of state police

Platooning regulation	States with regulation	Wyoming Bill/Recommendations
		and the state transportation department before starting platoon operations. If the plan is not rejected by either the department of state police or the state transportation department within 30 days after receipt of the plan, the person shall be allowed to operate the platoon.”
Presence of licensed driver in each vehicle in platoon	Michigan, Pennsylvania	**Not under consideration in the current draft bill** **Recommendation:** “If the platoon includes a commercial motor vehicle, an appropriately endorsed driver who holds a valid commercial driver license shall be present behind the wheel of each commercial motor vehicle in the platoon.”
Separate bill	Nevada	**Recommendation:** There should be separate legislation with regulations for truck platooning operations.

NATIONWIDE CAT RELATED ACTIVITIES

Since 2016, NHTSA has authorized the testing of 87 self-driving vehicles as part of 89 different projects in 20 states. The projects include 64 publicly operating low-speed shuttles in 45 cities [55]. Following the regulations implemented across the states, the various AV related activities and projects of the industry manufacturers or the state DOTs are summarized below.

Arizona

Uber's ADS testing in Arizona came to a halt after a crash involving Uber ADS in 2018 in which a pedestrian was killed in Tempe, Arizona [56].

Waymo (Google) began testing its Class-8 tractor trailers with autonomous features in 2017 in Arizona [57]. Since early 2017, Waymo has been testing its ADS-equipped Chrysler minivans by offering rides around Phoenix for a few hundred citizens in its "early rider" program. [58]. The operation of robo-taxi services beyond testing purposes was authorized through the executive order issued in March 2018 [59]. Since that time, several companies have announced or begun tests of delivery services and commercial activities such as delivery services using ADS-equipped vehicles in Arizona [60]. Recently, Waymo has opened its fully driverless ride-hailing service in suburban Phoenix to the public [61].

Arkansas

Walmart in partnership with Gatik has been operating a pilot grocery pickup using AVs on a two-mile route in Bentonville, Arkansas [62].

California

California is the home to the global tech center Silicon Valley and many of the CAV related tech manufacturer. As a result, the most active AV testing and deployment has been in the state with companies involved such as:

- Waymo/Google: Waymo was formed in 2016 [63], but Google begin testing of its AV prototypes in Mountain View, California roads since 2015 [64]. Besides closed course testing in Atwater, Waymo has been using some of the challenging conditions of the state to actively test in conditions, such as dessert or snow in areas like Death Valley and Tahoe [65], [66]. Since 2018, Waymo has been testing driverless AVs in the neighborhoods of Mountain View [67].
- Uber ATG: The ride sharing entity has resumed testing AVs in San Francisco from 2020 after halting the testing in 2018 due to a fatal crash in Arizona [68], [69].
- Cruise/GM: Cruise has an active presence in the Bay Area, currently operating 230 AVs in the city [70]. The company has been running a pilot program, "Cruise Anywhere," for San Francisco-based employees to use AVs as a rideshare service [71].

Other companies such as Toyota, Local Motors, and Nuro are carrying out AV testing operated by their test team. Livermore Amador Valley Transit Authority (LAVTA) are using Easymile AV shuttles to carry out public testing in Dublin [72].

District of Columbia

Uber is using their self-driving cars in manual mode to gather mapping data with the eventual plan to deploy AVs on the city streets [73]. Ford/Argo AI has also been gathering mapping data through their vehicles since 2018 and has been testing AVs since 2019 on the roads of the District of Columbia [74].

Florida

Argo AI/Ford have been operating their AV ridesharing testing in Miami since 2018 [75]. There are few driverless shuttles operating in Florida, some of which are targeted for senior living facilities [76], [77]. Waymo has been testing their AVs in the heavy rain conditions of Miami since 2019 [78]. The Florida Department of Transportation, Florida's Turnpike Enterprise developed a 475-acre and 2.25-mile-long test track, SunTrax [79].

Georgia

Georgia DOT in partnership with private-sector companies provided next-gen highway stripping in an effort to turn an 18-mile stretch of Interstate 85 in southern Georgia into a test bed for AV testing [80].

Waymo in 2018 began its testing in Atlanta, Georgia through their freight delivery using self-driving trucks [81]. The company also operated some of its self-driving minivans for mapping and public testing purposes in Atlanta in 2018 [82]. Besides Waymo, Navya operates a 12-passenger autonomous shuttle in the Atlanta suburb of Doraville [38].

Iowa

The University of Iowa has one of the country's leading CAV simulators and received a federal grant in 2019 to test CAV applications in rural areas [83]. A pilot testing program is being conducted by the University of Iowa along a 1-mile stretch of rural road near Cedar Rapids [38].

Maryland

The self-driving shuttle Olli, manufactured by Local Motors completed testing on public roads in National Harbor, Maryland [84]. The Steer Tech, since 2017, has been testing its autonomous parking solution in few MDOT approved parking sites [85].

Massachusetts

Aptiv and Optimus Ride have been testing their AVs in the Commonwealth of Massachusetts since 2017 with licensed human backup drivers [86]. Both companies have been granted approval from MassDOT and the City of Boston to conduct testing in daytime and nighttime hours and in light rain and fog.

Michigan

Michigan is home to several large CAV testing facilities, such as the Mcity, owned and maintained by University of Michigan [87]. Michigan is developing an AV corridor that stretches for more than 40 miles between Ann Arbor and Detroit, an initiative led by Cavnue and supported by an advisory committee consisting of Waymo, GM, Ford/Argo AI, and Toyota [88].

The Mcity testing facility at the University of Michigan is a 32-acre site with more than 16-acres of roads and traffic infrastructure capable of testing real-world scenarios for AVs [89]. As of this date, more than 15 industry partners of Mcity have conducted AV testing at the facility. The testing facility also operated a driverless shuttle pilot program from June 2018 to December 2019 in order to gather rider feedback for research purpose [90].

Michigan is involved with Ohio and Pennsylvania in a Smart Belt Coalition which involves both public and private sector partners. The focus of the coalition is commercial freight automation such as truck platooning [91].

Waymo has been producing self-driving vehicles in a Detroit plant since 2019 joining many other auto industry manufacturers in Michigan [92]. The company, since 2017, has also been using the snowy and icy conditions of Detroit to test their self-driving cars [93], [94].

Minnesota

The state has been conducting pilot tests and research initiatives for CAV technologies which included winter-weather related tests as well [95]. MnDOT, using the EasyMile shuttles, carried out an Autonomous Bus Pilot program in December 2017 and January 2018 to test the automated shuttle in mixed general traffic and winter-weather conditions [96].

Nevada

Las Vegas hosted an AV shuttle pilot in 2017 and 2018 [38]. Ride sharing company Lift, in partnership with software company Aptiv, has been operating a ride sharing pilot program in Las Vegas since 2018 and has been collecting customer feedback on the AV rides [97].

Ohio

Smart Circuit, an autonomous shuttle service, which is a collaboration between Smart Columbus and DriveOhio launched in Columbus in late 2018 [95]. Ohio in 2017 formed a Smart Belt Coalition with Pennsylvania and Michigan, involving both public and private sector partners with the focus being commercial freight automation such as truck platooning [98]. Smart Testing center opened in Logan County, funded by a partnership between the Ohio State University and the state of Ohio, which included an indoor highway track capable of simulating ice and snow year-round [38].

The Indiana and the Ohio DOT received a federal grant to prepare for, and advance the use of, semi-autonomous and autonomous truck traffic on the states' highways and I-70 has been chosen as the testing ground for the four-year program [99].

Pennsylvania

PennSTART is a training and testing facility initiated by the Pennsylvania Department of Transportation (PennDOT), Pennsylvania Turnpike Commission (PTC), and Penn State University (PSU) to address training and research needs for six key areas of transportation which includes CAVs [100].

PennDOT, PTC, Ohio DOT, the Ohio Turnpike, and Michigan DOT have jointly formed the Smart Belt Coalition with transportation agencies and universities in Pennsylvania, Ohio, and Michigan to focus on CAV initiatives [98].

Uber ATG, Ford/Argo AI, Aurora Innovation are some of the active AV testers in Pittsburg [101].

Texas

Texas has been one of the most attractive testing beds for AV industry manufacturers for quite some time now [102]. Currently, there are 21 active CAV pilot programs operating in Texas that includes connected vehicle applications, autonomous shuttle pilots, platooning, automated freight, ridesharing, and shared mobility from industry's leading companies [83], [103].

Ford/Argo AI in 2019 announced the testing of its autonomous taxi and delivery service on Austin roadways [104]. Uber has been gathering map data and driving scenarios for simulations purposes from Dallas, Texas [105]. Texas A&M University has been testing its self-driving shuttles in downtown Bryan, Texas with remote control operators [57]. Recently, Waymo and Aurora began testing of their AVs in Texas which largely included trucks and semi-trucks [103], [106]. Nuro in partnership with Kroger was scheduled to starts its self-driving transportation of pharmaceuticals in June 2020 to CVS customers in Houston, Texas [107]. The deliveries would be from one CVS pharmacy as part of its pilot program before branching out to serve other stores.

Utah

UDOT in partnership with the Utah Transit Authority launched pilot testing of an autonomous shuttle in April 2019 [108]. However, the pilot program was cut-short after NHTSA decision to stop the shuttle service run by EasyMile nationwide [109]. The decision was made after an incident in Columbus, Ohio where a passenger got injured.

Virginia

Virginia encourages AV testing by setting up 70 miles of Virginia highways as "automated corridors" and outfitting high-definition mapping and data acquisition systems to support AV testing [110].

Google (before rebranding to Waymo) in 2013 tested semiautonomous cars in Blacksburg in collaboration with Virginia Tech researchers [111]. Daimler Trucks and Torc Robotics have been testing self-driving trucks with a safety driver and an engineer to oversee the system on highways in southwest Virginia [112]. Fairfax County in collaboration with Dominion Energy is running a state funded pilot testing of autonomous relay shuttle in Fairfax, Virginia [113]. The shuttle is currently operating on a fixed route without any passenger and undergoing tests. The program is expecting approval from NHTSA by the end of 2020 to begin passenger operations. Researchers from various Virginia universities are overlooking the project with consideration to the pandemic situation where transit ridership is limited.

Washington

Currently, the self-certified companies are BMW of North America LLC, LM Industries Group Inc., NVIDIA Corporation, Optimus Ride Inc., Waymo LLC, and Zoox, Inc. However, state Department of Licensing don't have any record of how many of them have been on Washington roads [114]. Waymo tested its vehicle sensors in 2017 and 2018 rain seasons in the Kirkland area to determine how the sensors responded to rain [115], [116].

Torc Robotics in 2017 completed the first leg of a cross-country trip with a self-driving Lexus sport utility vehicle from Washington D.C. to Seattle, Washington [117]. The company claimed that the vehicle successfully maneuvered heavy traffic in Washington D.C., aggressive tailgating in Wyoming, heavy rains in West Virginia, and highway detours.

Peloton Technology, which is not defined as an AV manufacturer, went through the self-certification process and tested trucks' platooning capability on I-5 from Arlington to Linden that are not defined as self-driving or autonomous [116].

Wisconsin

The University of Wisconsin-Madison has been designated by USDOT in 2017 as one of the 10 automated vehicle proving grounds to encourage testing of new technologies [118].

LEGISLATIVE PRIORITIES AND RECOMMENDATIONS

The NCHRP provided a timeline, Figure 4, for CAV deployment reflecting anticipated commercial availability based on panel and stakeholder input [119]. This timeline has been provided so that states could start planning for deployment.

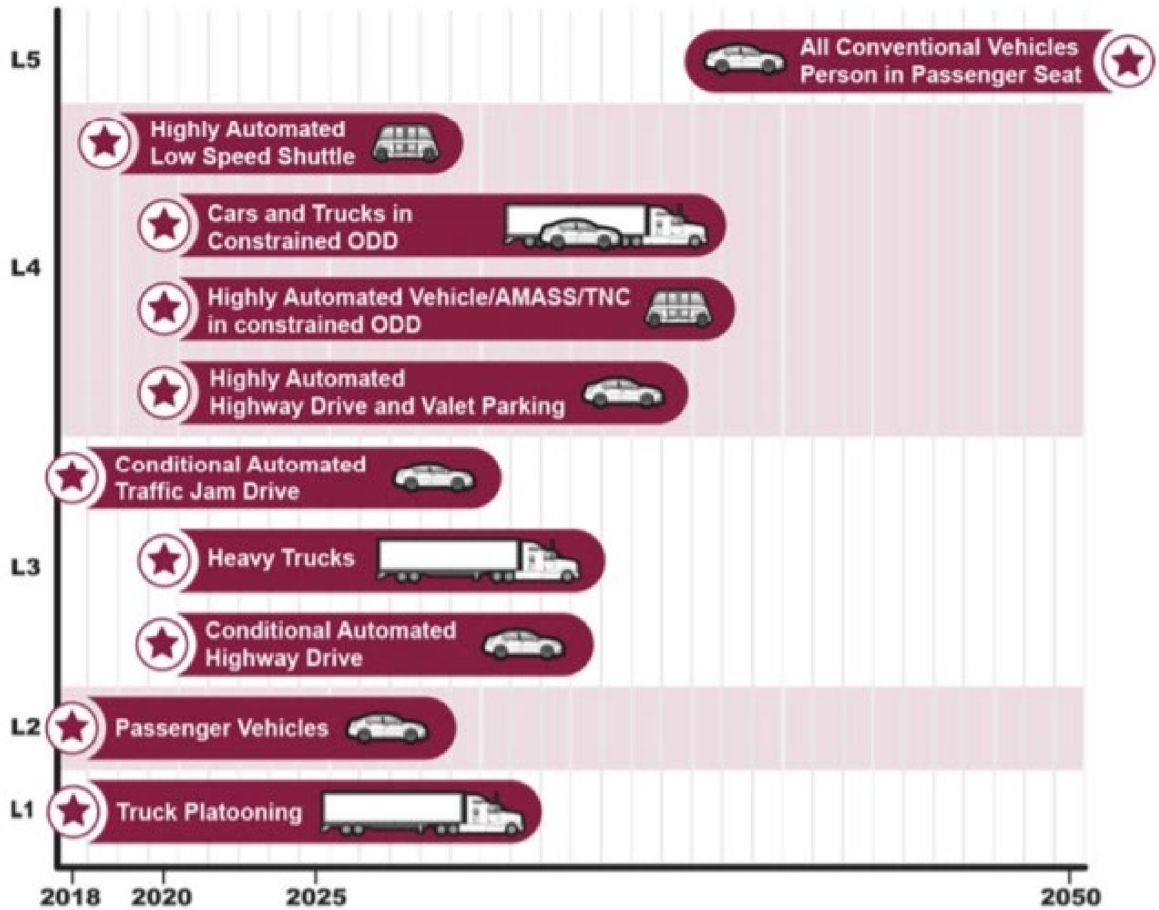


Figure 4 Timeline for CAV deployment. (Source: NCHRP 20-102(07) Implications of Automation for Motor Vehicle Codes)

The NHTSA developed a model policy framework, reflective of a state's regulation of the procedures and requirements that a CAV manufacturer or company must fulfill to gain authorization of operating CAVs in the state [120]. The framework includes the following eight thematic areas that are recommended for a state to address:

- Administrative: States should designate a lead agency such as the DOT and establish an interagency working committee or task force comprising of representatives from state agencies and stakeholders such as industry manufacturers, interested users. The committee should examine the existing laws and regulations and recommend necessary changes with respect of CAV deployment and testing. An application procedure or state guidance for testing CAVs in the state should be developed.
- Application for testing: A CAV manufacturer or entity interested in testing CAVs in the state should apply to the designated lead agency noting they are following FMVSS and any other standards set by the NHTSA. The applications should include, but not limited to the following: identification of the vehicle and test operator, safety and compliance plan, safety assessment summary, proof of ability to accept liability, and insurance requirements.
- Jurisdictional permission to test: Law enforcement agencies should be informed before authorizing the testing. The state may choose to restrict the testing in a specific area or within other stipulations. The vehicle should carry the vehicle-specific permit, title, and registration in the test vehicle.
- Testing by manufacturer or other entity: Manufacturers or entities must comply with all applicable federal law and NHTSA regulations. State should decide whether to allow testing with or without a human operator and what the role of the operator should be, whether the operator needs to be present inside the vehicle and in the driver seat. All crashes must be reported by the manufacturer or entity to the state's lead agency.
- Deployed vehicles and drivers: The regulations regarding enforcement/emergency response, occupant safety, motor vehicle insurance, crash investigation/crash reporting, liability, (tort, criminal, etc.), safety inspections, education and training, vehicle

modifications and maintenance, environmental impacts should be identified and addressed by the state.

- Deployed vehicles' registration and titling: Title and registration documents should reflect which vehicles are allowed to operate without a human driver. Any modifications or upgrades to the software or hardware should be reported to the state's lead agency.
- Law enforcement: Proper training and educations should be arranged for first responders and law enforcement agencies to interact with the CAVs and the operators/passengers. Provisions for distracted/impaired operator or passengers should be addressed in any legislation or regulations.
- Liability and insurance: State should decide on a procedure to allocate liability among the owners, manufacturers, software providers, operators, passengers, or others in a crash.

Chapter 3 IMPACTS ON INFRASTRUCTURE AND ROADWAY DESIGN

Autonomous Vehicles (AVs) have the potential to significantly transform the nation's roadways. AVs offer potential mobility and safety benefits but also introduce uncertainty for agencies responsible for the planning, design, construction, operation, and maintenance of the roadway infrastructure. The interaction of the AVs with the highway infrastructure can be categorized into four broad sections, as shown in Table 4. This chapter provides a synthesis of the reported impacts of AVs on infrastructure based on these elements, as found in the literature. Each section describes the current state of knowledge regarding the particular infrastructure category and the challenges moving forward with AV deployment in Wyoming.

Table 4 Highway Infrastructure Categories Impacted by AVs and their Corresponding Elements

Highway Infrastructure Categories	Elements
Physical Infrastructure	• Pavements • Bridges and Culverts • Roadway geometry
Traffic Control Devices	• Pavement marking • Traffic signs • Traffic signals
Multimodal Infrastructure	• Bicycle, pedestrian, transit infrastructure • Curb space • Charging facilities

PHYSICAL INFRASTRUCTURE

Although much about AV interaction with roadway infrastructure and other road users is unknown, AVs can be treated as another road user with particular set of requirements. It is widely anticipated that the majorly impacted physical infrastructure is going to be the pavements, bridges, and culverts [121].

Increased loading on physical infrastructure

The steering control and positioning systems of the AVs can be perceived to be more accurate than that of the human driven vehicles and consequently maintaining their position in the lane more precisely than humans [122]. Furthermore, the machines driving the AVs will be more situationally aware than humans, the reaction times for AVs will be much lower than humans. This means, where laws and users' comfort allow, AVs will be able to travel with significantly shorter headway, thereby increasing the capacity of existing roads. It may also be possible that, depending on the conditions, AVs will be able to operate at higher speeds more safely than human driven vehicles given the speed limit.

The coordinated movement of a sequence of vehicles via vehicle-to-vehicle communication and sensor technology is specifically known as platooning [123]. Platooning usually enables AVs, light or heavy, to travel with minimal headway and lateral offset to optimize the utilization of lane capacity and improve fuel economy. However, such operation increases traffic loading and accelerates structural deterioration.

Impact on Pavements

The advanced operating mechanisms of AVs may introduce pavement surface related issues. Changes in surface condition of the pavements can occur due to reduced wheel wander in transverse direction, increased lane capacity due to vehicle platooning, or higher traffic speed [124], [125], [126]. This may have positive or negative impact on pavements as reduced wheel wander and higher lane capacity may lead to higher pavement rutting as demonstrated by [126], [127]. However, the study Chen et al 2016 also found that increase in traffic speed would result in lower rut depth, thereby compensating for reduced wheel wander and increased lane capacity [95]. Therefore, according to these studies, the surface condition of the pavement with respect to AV operation may be dependent on various factors such as roadway type, speed limits, traffic conditions, vehicle platooning laws.

Autonomous trucks are likely to cause more damage to the pavement compared to the lighter AVs. Few studies evaluated the impact of the positioning of autonomous trucks on long-term pavement performance [128], [129]. The main conclusion from the studies was that repeated positioning of trucks in the same location accelerated the pavement damage measured in terms of rut depth and fatigue. This indicates that pavements are likely to deteriorate faster with the operation of autonomous truck platoons.

Impact on Bridges and Culverts

Platooning of commercial vehicles is likely to change the loading on bridges. The current roadway infrastructure was not designed to accommodate vehicle platoons. Typically, bridges and culverts are designed by assuming certain parameters such as the number of vehicles likely to be on the structure at any one time, traffic composition, axle spacing and loadings. Furthermore, in rural areas, engineering judgement may even allow subpar design standards to spare resources.

Historically, bridges in the U.S. have been designed for “truck trains”, but the load models are unlikely to account for a connected sequence of multiple trucks and not just one or two [130]. The majority of the bridges in the U.S. inventory were designed for two different live load models (Figure 5), older HS20 live load [131] and the current HL93 live load [132]. Using these live load models, U.S. bridges have been designed under three different methodologies.

- Before 1975: Allowable Stress Design (ASD) method
- Between approximately 1975 and 2004: Load Factor Design (LFD) method
- Most recent: Load and Resistance Factor Design (LRFD) method

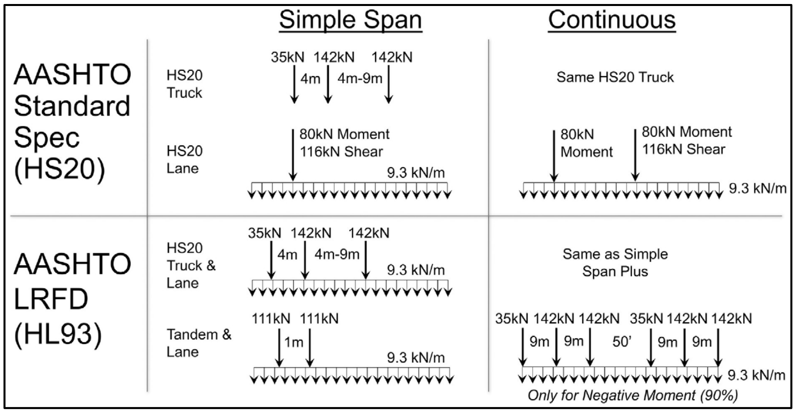


Figure 5 HS20 and HL93 live load models, Source: R. Tohme and M. Yarnold [133]

It is necessary to consider whether the impact of vehicle platooning will be significant and whether the load models used in the design of structures will be adequate with this change.

Impact on Roadway Design

The impact of AVs on roadway or more particularly highway geometric design is an emerging area of research. Typically, geometric design refers to the physical design of a roadway configuration such as horizontal curve, rate of change of vertical slope to connect roadway segments with varying grades. The design of these highway elements is mostly governed by vehicle kinematics, dimensions, and sight distance of humans for safe stopping [134]. The impact of AVs on geometric design with various levels of automation from no autonomy (L0) to full autonomy (L5) was investigated [135]. The appropriate design criteria, such as reaction time, sensor height for each autonomy level were selected and sight distance and length of vertical curves were computed for each scenario. The study concluded that as the autonomy level increased, stopping sight distance decreased, and design speed increased while the length of crest and sag vertical curves decreased. A recent work by Khoury et al 2019 explored the effects of AVs on highway geometric design and concluded that AVs could lower the economic and environmental impacts of highways construction as it reduces the amounts of cut and fill required to reach the subgrade level [102]. However, the authors proposed that grades and more factors, such as target height of objects, should be accurately accounted for in estimating sight distances for AVs.

The machine vision of AVs is facilitated by LiDAR and vision sensors, cameras. Vision sensors are subject to the same limitations as human sight in darkness and adverse weather conditions. While darkness is not an issue for LiDAR, this technology has thus far shown limited success in situations with inclement weather [136], [137]. Thus, it is still unclear how the current technologies used on AVs overcome one of the major limitations with human sight, that is, line of sight. For example, at this point, it is not reasonable to assume that an AV could detect an obstacle in the roadway such as fallen boulders or a wildlife around the bend of the curve shown in Figure 6 any sooner than a human could. In case of only automation with no connectivity, particularly for rural areas, the limitation of sight distance will persist for AVs when there are obstacles, such as crest curve or a sharp bend [138].

Figure 6 A series of sharp curves in Wyoming (Source: AAroads)

The review of literature by Farah et al., 2018 based on the impact of AVs on highway infrastructure synthesized that the existing literature mostly assumes full penetration (100 percent) with automation level 4 [139]. Several researchers indicate that standards regarding the width of the road could be reduced given that all vehicles are automated and connected [140], [141]. This could potentially provide for additional lanes, possibly dedicated to platoons. However, it must be acknowledged that there is a lack of studies which investigate the potential changes in the physical infrastructure in an intermediate stage of mixed traffic of automated and traditional vehicles.

Current infrastructure conditions in Wyoming

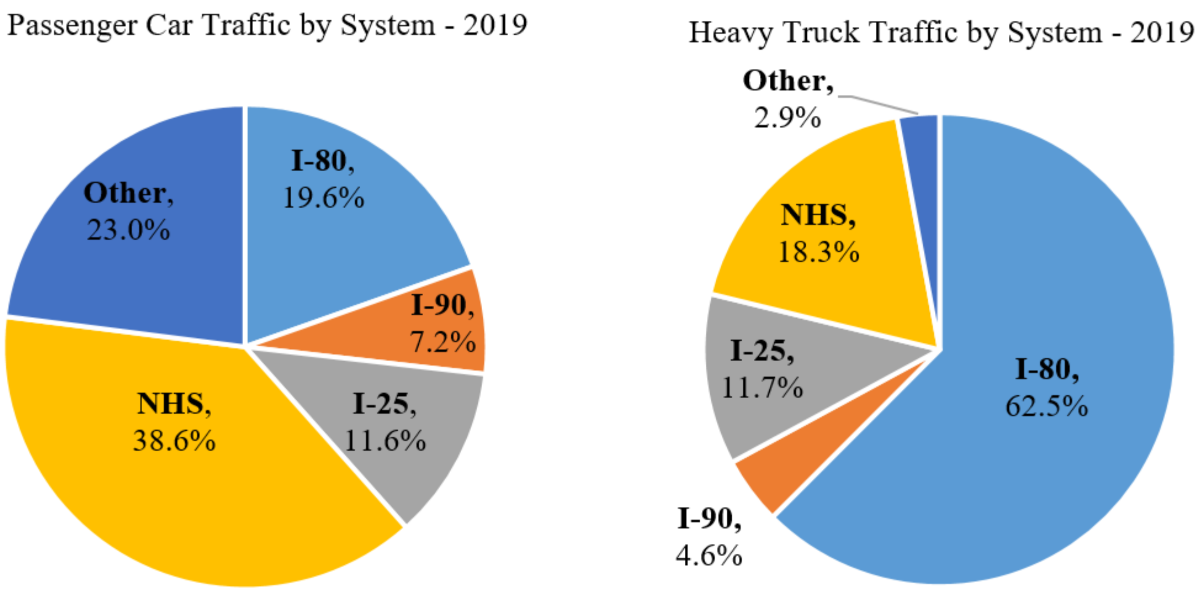


Figure 7 Traffic levels by system [109]

While majority of passenger car traffic is carried by the NHS or Other highways, percentage of heavy truck traffic is highest on the I-80. The overall statewide truck vehicle miles travelled (VMT) percentage is 11 percent of all traffic VMT and the interstate truck percentage in terms of VMT is 38 percent of all traffic [142]. Accelerated pavement rutting and fatigue due to reduced wheel wander, reduced lane offset, increased lane utilization, and higher coordinated speed are likely to be some of the impacts of truck platooning operations on highways. It is imperative to determine whether the highway pavement structures are in acceptable shape to withstand these new impacts. Currently, the percentage of good to excellent condition pavements is around 60 percent and is projected to decrease as illustrated in Figure 8. Furthermore, the performance ratings of bridges on the state highway system reveals that majority of bridges are in fair to poor condition, as shown in Figure 9.

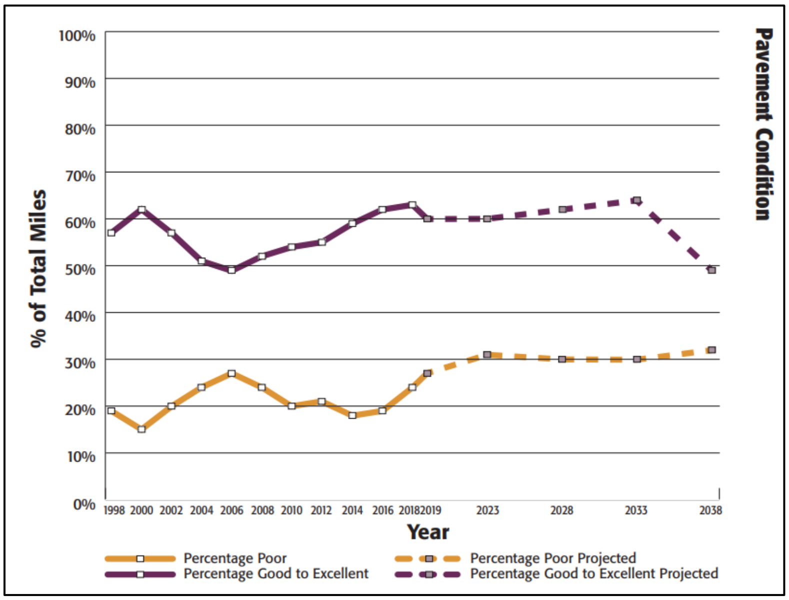


Figure 8 State highway system performance trends, Source: WYDOT[143]

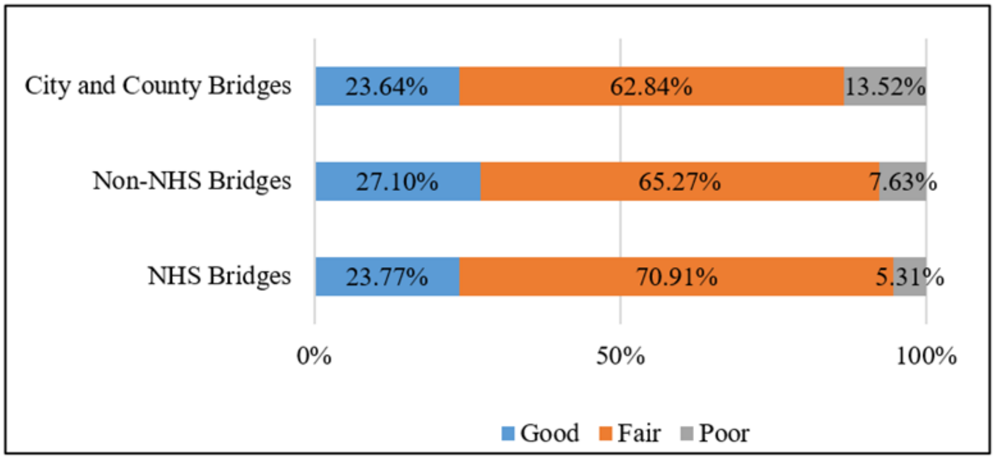


Figure 9 Performance Ratings for Bridges on the State Highway System in 2019, Source: WYDOT [144]

Maintenance of Physical Infrastructure

AV operation can have detrimental impact on pavements. However, it is still unclear how the AVs react to pavement defects such as pot holes, edge wear, and debris [145]. Defects such as this will require regular monitoring and maintenance will need to be carried out once the level of defects surpasses beyond the level at which AVs can operate safely without any disruption. Pavements that are likely to experience AV platooning, especially truck platooning will require more aggressive monitoring and possible maintenance. Lateral offset of AVs in a truck platoon can provide some balance to the damage done by repetitive loading of AVs over the same path. However, the concept requires more research and attention to assess the effectiveness [145].

Besides the structural condition of the pavements, the external surface condition is also crucial to safe AV operation. This particularly applies to regions where heavy rainfall or snowfall may result in wet pavements or pavements covered in snow resulting in AVs to detect obstruction and initiate failsafe conditions [146]. Minnesota DOT (MnDOT) conducted a shuttle bus pilot project in 2017-2018 that aimed towards preparing for AV operation in mixed general traffic and winter weather conditions particularly snowy and icy pavement conditions [147]. The AV shuttle sensors detected falling snow, blowing snow, snow on the test track as obstructions and made frequent stops. Much of the solution to this problem is contingent on the development of more advanced sensors and training the machine to detect and maneuver adverse weather conditions [148].

Roadway maintenance during adverse weather conditions is also a key issue to address for states with prevailing winter weather conditions (snowstorms, blizzards, blowing snow). In few of the AV testing conducted in such weather conditions, the pilot programs demonstrated the shortcomings of AVs in adverse weather [147], [148], [149]. Therefore, a short-term strategy may need to be implemented to keep roadways clear of snow with aggressive passing of snowplows after a snowstorm if the roadway is expected to experience high volume of AV movement. However, when more advanced sensors or smart pavement technologies are developed which can enable the AVs to detect and maneuver snow safely, the aggressive snowplowing strategy can be relaxed.

It is quite evident that the overload and multiple presence of coordinated vehicles on bridges and culverts need to be evaluated [133]. The AASHTO provides a methodology for bridge evaluation [150] which can be used to calculate load ratings and determine whether the bridges are adequate to withstand the impact of the new type of loads due to platooning.

The design standards of bridges and culverts may need to be revised if these structures are found to be inadequate in accommodating vehicle platooning. AVs in a platoon are likely to operate at high speeds and interact dynamically with bridges and their barriers as well. As a result, design standards of barriers may also need reconsideration. Not only design, but also the way how these structures are managed need to be changed. Monitoring intervals may need to be increased or done at real time with the help of technology to ensure safe and efficient operation of AVs on these structures [145]. Improved asset monitoring programs can reduce the impact of AV operations on critical physical infrastructure.

Emerging Technologies

Currently, CV technologies are already being implemented as part of a pilot program conducted on the interstate I-80 of Wyoming [151]. Information such as forward collision warning, situational awareness (such as weather alerts, speed restrictions, road closures, and incidents), work zone warning, spot weather impact, distress notification can be shared among the AVs to enhance safety and operations. Research on using on-board sensors and phenomenon such as tire microslip to detect more accurate and localized road surface condition provide new opportunities for more refined information sharing via CV or AV technologies [152].

There are some other emerging technologies that can provide solutions to the new challenges that the AV operation presents. Concepts of smart pavements, which can transmit digital signals to the AVs, have been developed by researchers and AV technology entities [153], [154]. One of those concepts includes mixing the asphalt material with magnetic particles that will allow signals to be transmitted to the AVs [155]. There is another ongoing initiative to develop smart roads by embedding precast concrete slabs with digital technology and fiber optic connectivity [156]. The purpose of these emerging technologies is to enable the pavement structure to transmit information to the AVs related to road surface and environmental conditions. The AVs can then react to the information provided by taking necessary actions such as changing lanes to avoid defects on pavements, reducing speed in adverse weather or determining whether the conditions are unsafe for driving. The DOTs in Missouri and Colorado are contemplating the idea of integrated roadways [157]. Solar roadways are also one of the emerging technologies with the potential for providing solutions to AV related pavement issues, with the key one being heating the pavement to prevent snow and ice accumulation [158].

Strategies using emerging technologies may need to be developed to mitigate the impact of increased loading on bridges due to AV platooning. A study by Lipari et al., 2017 provided one such solution to increased loading on bridges by using a gap control system [159]. An infrastructure-to-vehicle communication (I2V) can be set up with a gap control device based on site-specific traffic characteristics and structural conditions. The device can then communicate to the vehicles in platoon the distance they may need to maintain from the leading vehicle to safely transverse the structure. The results from the study showed that, with 90 percent trucks responding to the device, the traffic loads on the bridge can be reduced by as much as 47 percent. While this mitigated bridge loading strategy may save maintenance costs, the implementation costs against the benefits may need to be evaluated properly.

TRAFFIC CONTROL DEVICES

Identifying the infrastructure needs for CAVs is essential to help local agencies and DOTs to get prepared to accommodate such emerging technologies. Road furniture with a focus on items that provide warnings, regulations, directional information, and operation were the main focus of researchers and CAV manufacturers to provide an efficient Vehicle-to-Infrastructure (V2I) communication. Road marking, signs, and signals are the three main categories that transportation agencies need to provide extra attention to, as CAVs rely heavily on these items for safe operation.

Road markings are used to convey official information and to provide guidance for different road users. Uniformity and consistency of marking are crucial for CAVs to minimize confusion and uncertainty about their meaning. The same concept is applied to traffic signs as they provide instructions and regulations for vehicles and pedestrian on the appropriate operation on the roadways. Traffic signs could be located at any geographic location on the road. It could be located at intersections, interchanges, weaving sections, merge and diverge sections, tunnels, and bridges as well as straight roadway segments. Unlike traffic signs, traffic signals are only located within intersections and midblock areas to regulate conflicting traffic at a specific geographic location. In order to accommodate the new emerging technologies that will help in promoting traffic safety and operations, the surrounding environment must evolve as well. Upgrading the standards and specifications of these three categories will help in accommodating the needs of CAVs in the near future.

Infrastructure will need to evolve to support human vision as well as machine vision, which is highly utilized by CAVs. Warnings and messages provided by road marking, signs, and signals should be designed in a digital fashion that can easily communicate with CAVs. Additionally, it should keep the analog design that can communicate with human vision. This will enable CAVs to timely interpret and respond to navigate efficiently on our roadways. One of the ongoing efforts to support the operation of CAVs, FHWA is updating the Manual on Uniform Traffic Control Devices (MUTCD) to include advances in traffic control device that supports automated driving systems, which will be published soon. In the following sections, current adopted plans, future needs, and recommendations will be provided for each of the three road furniture categories, such as marking, signs, and signals.

General

Uniformity and quality of traffic control devices are considered the most challenging issue that face the deployment of CAVs. In coordination with several automotive industry associations, the National Committee on Uniform Traffic Control Devices (NCUTCD) aimed to identify the modifications needed for the existing traffic control devices to accommodate the operation of CAVs. A task force was established with the focus on identifying how the CAVs will impact the MUTCD. This task force was formed by the Markings Technical Committee (MTC) of the NCUTCD.

Three areas were recognized by the MTC Automated Driving Systems (ADS) RFI Task Force to support the automated driving systems (ADS) [160]. The three identified areas were uniformity, quality, and maintenance.

The non-uniform application of TCDs is considered a major issue facing the operation of CAVs. Generally, States across the US adopt the regulations provided in the MUTDC. However, several states had an additional supplement manual that might vary from the original specifications provided in the MUTCD, as shown in Figure 10. Additionally, there is flexibility in the MUTCD regulations, where it provides optional sections that allow for variation in its application.

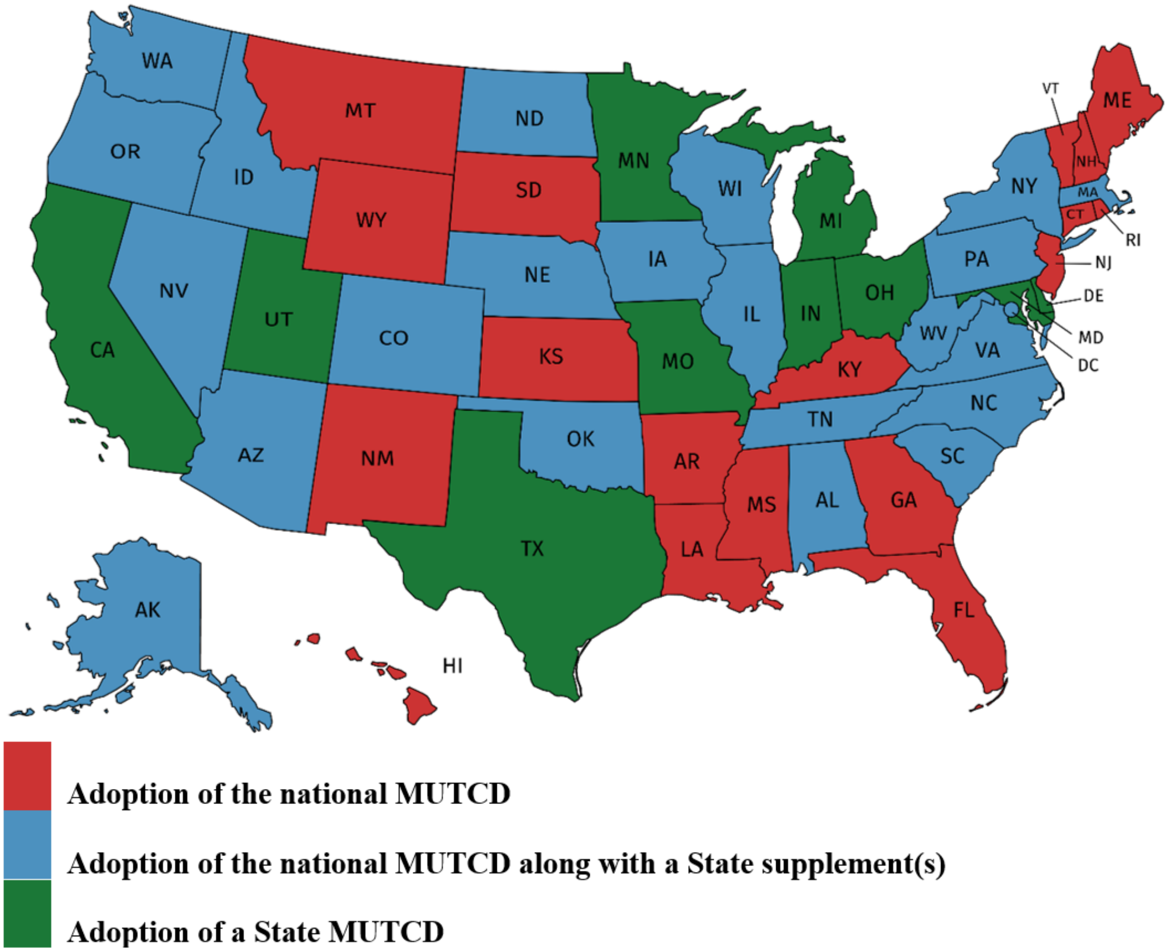
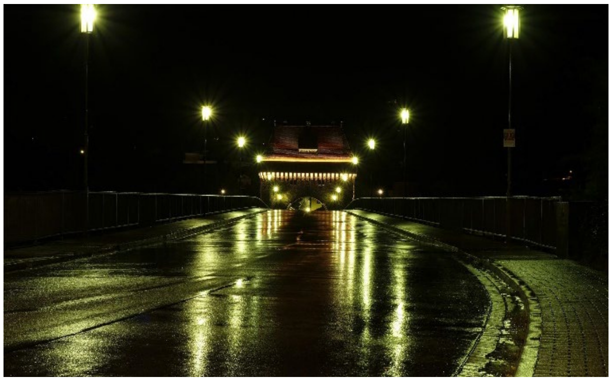


Figure 10 Adoption levels for the national Manual on Uniform Traffic Control Devices (MUTCD). **Source: MUTCD website (https://mutcd.fhwa.dot.gov/resources/state_info/index.htm)**

To support safe and efficient operation of CAVs, quality of marking and signs is essential. The CAVs mainly rely on cameras, sensors, and LIDAR to sense and visualize the surrounding environment. Figure 11 shows an example of how machine vision could identify the surrounding pavement marking for safe driving decisions. Additionally, weather conditions have a significant impact on the machine vision detectability of pavement marking. These conditions could be concluded as rain, low sun, high glare, fog, and snow. The provided contrast between pavement color and markings should be evaluated as it is mainly intended to improve human vision, while it may not be suitable for machine vision. Figure 12A to Figure 12E shows examples of the common issues that hinders machine vision to identify pavement marking.

Figure 11 Example of road marking identification by CAV algorithms. Source: S. Vacek, C. Schimmel, and R. Dillmann [161]

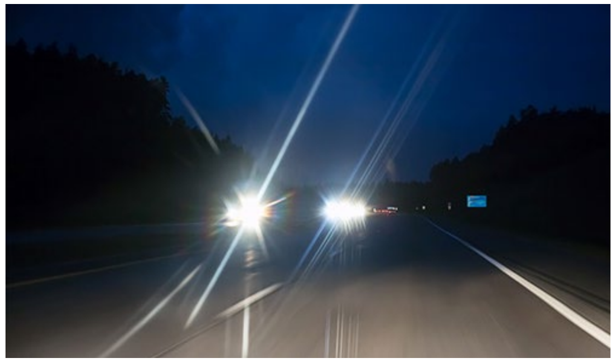
Other issues that are directly related to maintenance are poor marking removal and faded marking. These issues could particularly cause confusion for the machine vision to identify the driving lanes. This magnifies the importance of providing comprehensive maintenance plans to provide clear and visible traffic control devices. Several researches have shown the importance of providing good road marking [162], [163], [164], [165]. Good road marking enhances the overall safety on the roadways. Additionally, it will help to provide safe maneuvers and driving conditions for automated driving systems.



A-Subfigure A - Rain and wet surface. Source: Bru-no from Pixabay
[https://www.wvxu.org/post/why-are-road-lines-so-hard-see-rain#stream/0]

B-Subfigure B - Foggy conditions. Source: for and no lights by Leerberg
[https://henrikleerberg.wordpress.com/2015/12/21/fog-and-no-lights/]

C-Subfigure C - Low sun. Source: Photo by Ralph Bouwmeester
[http://www.sunposition.com/news/worldherald/sun-glare-dangers.html]



D-Subfigure D - Glare due to headlights of vehicle in the opposing driving direction. Source: Night Driving Accidents in Alabama [https://www.hornsbywatson.com/injury-law-blog/night-driving-accidents-in-alabama]

E-Subfigure E - Snow and ice covering the pavement surface. Source: Driving in Snow - A Colorado Driving Adventure [http://coloradoguy.com/driving-in-snow/photos.htm]

Figure 12 Pavement conditions potentially impacting machine vision detectability of pavement marking

Pavement Marking

The performance of pavement marking degrades over time due to wearing factors. Pavement marking is considered an important ODD as it is providing regulation, warnings, and guidance for road users. The AV community identifies pavement marking as a crucial factor that ADS rely on heavily. The cameras and the machine vision algorithms basically rely on identifying the pavement marking in visualizing the driving environment. Several ADASs utilize pavement marking in their main operation, such as lane departure warning, lane-keeping assist, and lane centering control.

According to the National Committee on Uniform Traffic Control Devices (TCD) Connected-Automated Vehicle (CAV) Task Force, several suggestions were provided to accommodate ADS [166]. Below are the suggested areas being the pavement marking needs to be updated:

- Painted Lane- Boundaries with Good Contrast

  Increasing the painted marking contrast with the pavement surface should be enhanced, especially when exists on concrete pavement. Lane marking and yellow edge lines could be surrounded with black marking to enhance the visibility of each line type and color.

- Reflectivity

  It was suggested to determine a mandatory restriping at some percent of pavement marking fade. Additionally, highly reflective pavement markings for driving are suggested for night and in rain conditions.

- Edge Lines Versus Curbs

  It is suggested to add edge line markings even when curbs are presented, when having a center line painted on the pavement. This would increase the contrast and the visibility of the lane edge thus supporting the ADS operation.

- Non-Dedicated Exit Lanes

  Dashed lines along an exit should be provided to guide the traffic toward the main driving path. Areas with no sufficient guidance shall be avoided.

- Emergency Areas/Shoulders

  Emergency areas shall always be provided on the side of the lane for all freeway, as well as for dedicated lanes, such as HOV lanes.

- Botts Dots

  Botts dots shall be generally avoided. If required, it should be supported by a painted line below to increase visibility by machine vision.

- Short Dashed Lane Markings Indicating Exit Only Lanes

  Providing specific standards for dashed lines should be provided. These standards should include marking length (> 3ft), marking width (> 10in), and gaps between marking (> 5ft).

  No other markings or obstacles shall be provided between the markings.
- HOV/Express Lanes

  Standardizing and providing uniform entrance and exit scenarios for dedicated separated lanes. This could be achieved by separating the main flow from the dedicated lanes using a special type of marking (2 or 3 solid lines), providing a yellow line separation between the main flow and the dedicated lanes, and adding dashed lines at the exit and entrance of these lanes for uniformity.
- Hatched Areas

  Special marking should be provided for non-drivable areas at the created free spaces. Crossing lines or other special marking shall be provided.
- Pavement Marking Items

  Other recommendations were provided for specific areas, where uniformity, increasing contrast and providing marking were the main solutions. These areas were carpool lanes, bike lanes, large free space areas, lane endings and lane splits on highways, and speed bump notifications.

Other detailed recommendations were suggested by the technical committee on June 2019 and approved by the NCUTCD council in January 2020 [167]. These recommendations were proposed changes to the current MUTCD. It is worth mentioning that a new version of the 2009 MUTCD has been approved and will be published soon. These recommendations were mainly related to longitudinal whiter pavement marking. The MUTCD updates included:

- Increasing the normal line width from 4 to 6 inches for interstate and freeways and other roads with posted speed of 55 mph and ADT of 6,000 VPD or greater. Otherwise, 4- to 6-inch-wide lines could be used.

- Width of wide lines shall be 8 inches or more when used with 4-inch normal lines and 10 inches or more when used with 6-inch normal lines.
- 15-foot line segments and 25-foot gaps for broken lines should be adopted on interstates and freeways.
- Dotted lines shall be installed on exit ramps with tapered deceleration lanes.
- A normal width dotted white line extension may be installed for passing, climbing or truck lanes.

According to Wyoming pavement marking manual [168] and the Manual on Uniform Traffic Control Devices (MUTCD) [169], the commonly used width of longitudinal pavement marking is 4 inches in width. It is stated in the Wyoming pavement marking manual that the Wyoming Department of Transportation (WYDOT) is responsible for adopting a manual for a uniform system of traffic control devices, which is consistent with the MUTCD. As previously mentioned, the NCUTCD is issuing an updated version of the MUTCD, where the longitudinal pavement marking will have a standard width of 6 inches. This will require executing a statewide plan to maintain the longitudinal marking for the three interstate roads (Interstate-80, Interstate 90, and Interstate 25) as well as all the rural highway with speed limit above 50 mph. Additionally, gore areas located at entrances and exits from highways and interstates should include a chevron marking to follow the new requirements provided in the updated MUTCD. Furthermore, for broken lines (lane marking), instead of adopting a 10 feet line in length with a gap of 30 feet gaps, a 15 feet line segments and 25 feet gaps for broken lines should be adopted on interstates and freeways.

Signs

Traffic signs was also a priority for the NCUTCD as it provides regulations, warnings, and information for road users as well ADS and ADAS. Camera-based Traffic Signs Recognition (TSR) system is the main technology used to identify, read, and interpret the traffic signs for safe operational decisions. High resolution cameras are used to accurately identify traffic signs, adopting advanced machine vision algorithms to recognize the information communicated in each provided sign on the roadside. However, other challenges might provide complications to accurately read the traffic signs. Uniformity, amount of light, weather, and maintenance could be concluded as the main challenges that affect TSR. Accordingly, several recommendations have been provided by the National Committee on Uniform Traffic Control Devices Connected-Automated Vehicle (CAV) Task Force to overcome these limitations [170]. These suggestions included general recommendations as well specific recommendations for different types of signs.

NCUTCD General Recommendations

- ***Standardize all traffic signs throughout the entire country***

Although providing consistency for traffic signs standards across the US is important and will help in facilitating the TSR, the different sign designs suffer from several limitations. Thus far, Europe has much of the successful work in the area of TSR compared to the US. The main signs used in developing the TSR are the signs provided in the Vienna Convention on Road Signs and Signals [171]. The rest of the world designs their traffic signs similar to Europe. Difference between the traffic signs for the US and the Europe signs matters significantly. European signs employ different shapes, border width, and colors that are distinct for each class of signs, which enables easy detection and recognition of signs from the background environment. The vast majority of US signs have rectangular shape with white background color and black text or symbols. Warning signs in the MUTCD might have yellow, orange, fluorescent yellow or fluorescent yellow green colors placed on a rhombus shaped sign, which provides less distinctive and visually weak classification for machine vision. Figure 13 shows a sample of signs that clarifies the difference between the US signs and Europe.

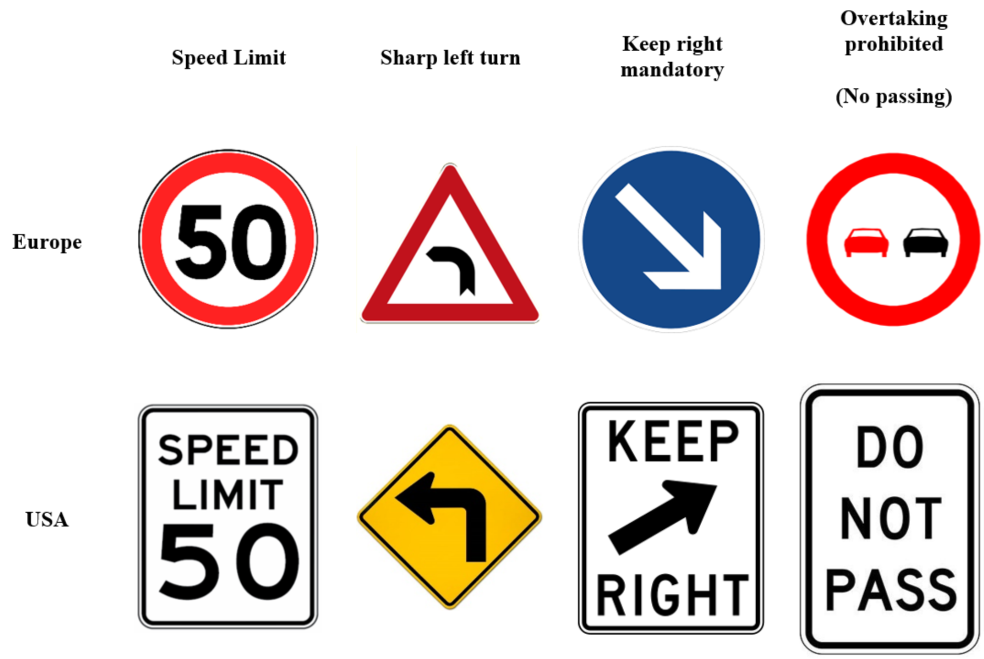


Figure 13 Sign example from US and Europe, Source: MUTCD and the Traffic signs Manual

General recommendations to have unified and standardized signs as traffic control devices would include:

- ***Use mainly pictograms, limit use of text. In situations where text is necessary: The content of the text shall be standardized***

Signs that include text in it are not as easy as pictogram signs for road users as well as TSR systems. Unique symbols and shapes are easier to identify and recognize by machine vision as they do not need any Optical Character Recognition (OCR) technology. Adding text to signs complicates sign recognition as it has to contend with non-uniformity of size, font style, and text location. Additionally, TSR systems must differentiate between essential and non-essential signs. Moreover, recognizing signs with text takes longer time compared to pictogram signs, which could be a potential issue with interstate and freeways where operating speed is high. Limiting the text and replacing it with symbols is a promising solution for easy recognition of traffic signs. When text cannot be replaced, standard and uniform wording could be used, in which it could also be identified as patterns instead of text. Figure 14 show examples for signs in the MUTCD including text and the provided pictogram alternative.

Figure 14: Example of signs with text and their pictogram sign alternative, Source MUTCD

- ***Do not allow unique state specific traffic signs.***

Eliminating state specific signs would provide consistency and uniformity of sign across the whole state. This will simplify the recognition process of the traffic signs. Several states adopt their state specific MUTCD, where it includes several added sections or eliminated sections form the MUTCD. Non-standard signs exist in the state specific MUTCD. For example, Texas and California have their own MUTCD where several non-standard signs are adopted. Figure 15 shows examples of several signs that does not exist in the national MUTCD.

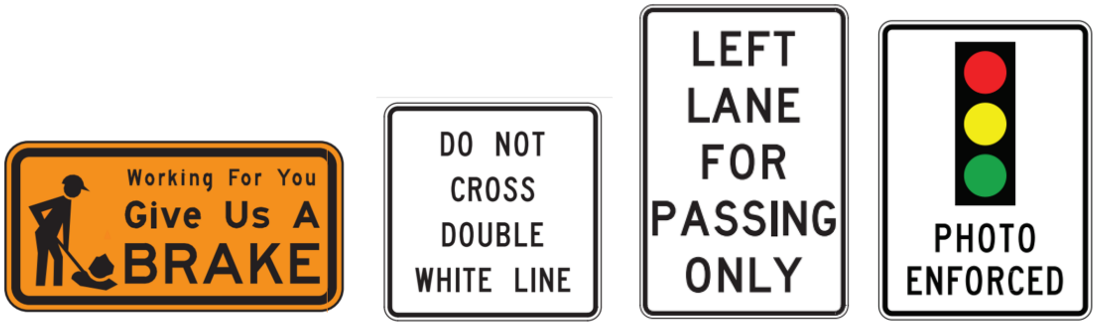


Figure 15 Examples of non national MUTCD standard signs, Source: Texas MUTCD

- ***All road signage should have good retroreflective background.***

Ensuring suitable retro-reflectivity for traffic signs will enhance their conspicuity, which enhances the overall traffic safety [172], [173], [174] as well as helping machine vision to accurately recognize traffic signs.

All the provided general recommendations mainly are related to enhancing the conspicuity of traffic signs as well as providing uniform and standard design in all the states. Achieving these recommendations will enhance the identification and recognition of traffic signs using machine vision. A dual prong benefit is also achieved, as it will also help regular motorists and road users to recognize the traffic signs efficiently. Additionally, the National Committee on Uniform Traffic Control Devices (NCUTCD) provides further recommendations for unified adoption of signs. These recommendations could be concluded as follows:

- Recommendations for Electronic Signs

Several suggestions were recommended for electronic signs, where standardizing them was the main approach. Retroreflective or illuminated White color should be provided for all electronic signs with black color text. Rectangular shaped signs should be used with standard length and width. Entire sign should be illuminated with a flicker/refresh rate above 200 Hz to be easier for the camera to detect. The location of the sign should not be above 17 feet in height from ground to the bottom of the sign.

- NCUTCD Recommendations for Speed Limit Signs

Speed limit signs have to be associated with its specific route or lane. In case of parallel roadways, machine vision might be confused to determine the appropriate operating speed.

- NCUTCD Recommendations for School Signs

The design of school speed limit signs should be standard, in which it includes a yellow "SCHOOL" sign above a rectangular speed limit sign with standard dimensions. For conditional school signs, standard text shall be provided. If the school sign is electronic, a refresh/flicker rate above 200 Hz should be used. Moreover, signs should be placed on a height that does not exceed the 17 feet from ground tot eh bottom of the sign. At the end of the school zone, a rectangular sign including the text "END SCHOOL ZONE" should be placed.

- NCUTCD Recommendations for Future Signs

The concept introduced by 3M to place a 2D Infrared-readable barcode could be a potential solution for future sign recognition. An imbedded barcode that identifies each specific sign could be placed on the signs using an optically transparent material [175]. This will enable IR cameras to read the barcode while human can still read the sign clearly without any interference. 3M mentioned that the barcode could be identified from a range up to 95 ±16 m in day light and 86 ±17 at nighttime. Figure 16 shows how the cameras read and recognizes the different signs.

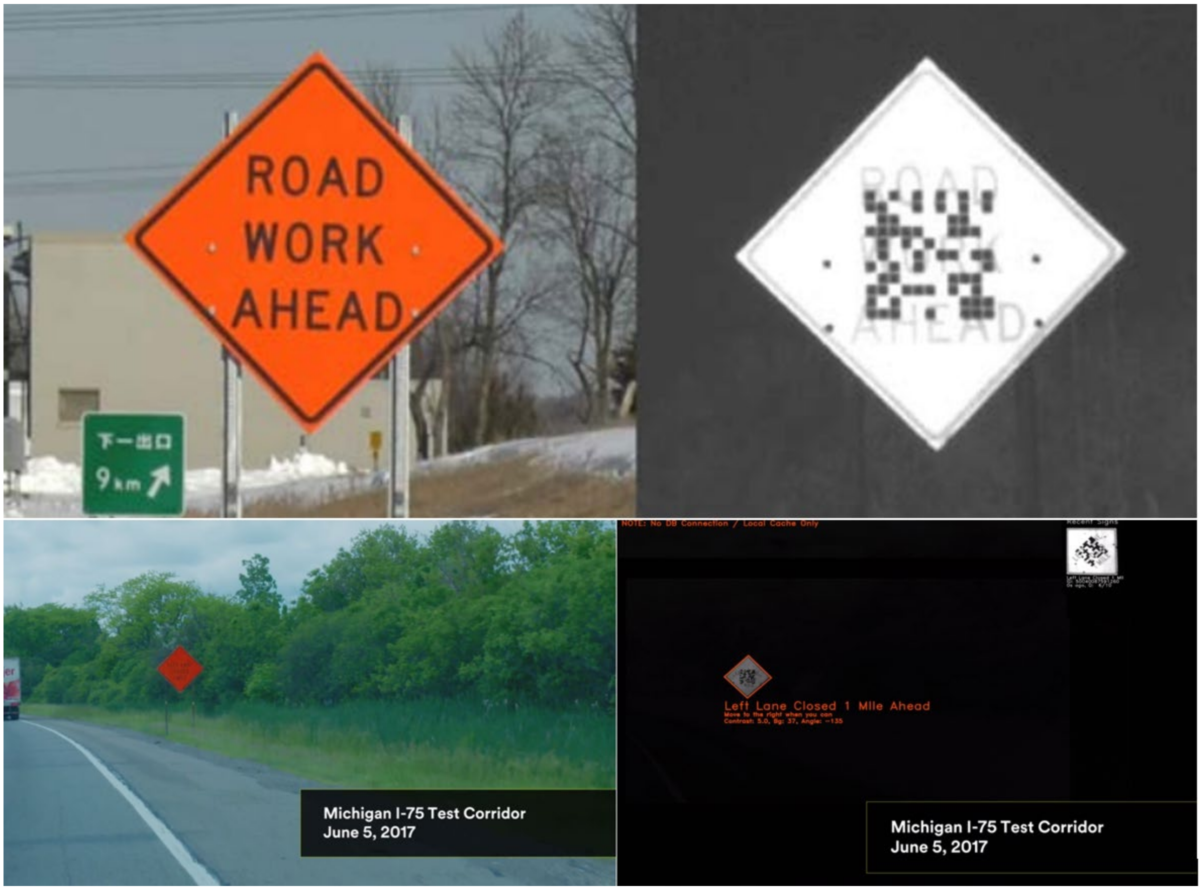


Figure 16 Machine vision to recognize traffic signs using barcode by 3M. Source: "Invisible" 2D Bar Code to Enable Machine Readability of Road Signs – Material and Software Solutions - 3M Transportation Safety Division

It is unquestionable that WYDOT exerts all the possible effort to keep Wyoming traffic signs maintained and up to standard. WYDOT has more than 70,000 signs distributed across Wyoming [176]. Fading, beating, gunshots, and paintball shots are among the factors that deteriorate the signs' performance. Signs facing the south direction fade sooner than other signs due to the sun's direction while west facing signs take beating from wind, dust, and gravel. Technology and experience are mainly used to identify traffic signs that need maintenance. Reflectometer readings are used to assess the reflectivity of the traffic signs. All signs in Wyoming are checked on a yearly basis to ensure high performance quality for road users.

Traffic signs in Wyoming is generally in accordance with the MUTCD [177]. It is generally recommended to adopt pictogram sign alternatives provided in the MUTCD instead of text. For electronic signs, a flicker/refresh rate should not be less than 200 Hz for easy machine vision recognition.

Signals

V2I communication could be used to send signal phasing to CAVs, which can increase the efficiency and safety at intersections. Adopting an Intelligent Intersection Control System (IICS), in which dynamic SPaT could be assigned based to CAV arrival rates based on V2I and I2V communication would enhance the operation and safety of road users. However, to obtain optimal efficiency, high CAV penetration rates should be first achieved. Currently, the NCUTCD provided several recommendations that could be utilized to currently help in accommodating CAVs. Uniformity in traffic signals placement, illumination, shape, refresh rates, and intensity could be helpful.

It is preferred to have vertical traffic signal over horizontal ones as they are particularly problematic. The refresh rate should be greater than 200 Hz. Traffic lights should have a strip shape, where blocks, L-shaped, T-shaped are not allowed. When required, a retroreflective sign could be placed for guidance. Traffic lights at the same location for different vehicles of other road users should not be close to each other to avoid confusion. As a general recommendation, Refresh rate and signal shape has to follow the recommendations provided by the NCUTCD CAV task force.

MULTIMODAL INFRASTRUCTURE

Multimodal infrastructure in this review can be referred to as the infrastructure elements that provide support to the AV modes, facilitate connection between AV and non-AV modes, and the general transportation system. Such elements include vulnerable road user facilities, curb space management, and charging facilities for AVs/EVs.

Infrastructure for vulnerable road users

The reason to consider the safety of vulnerable road users had become more evident after the fatal crash between a pedestrian and autonomous Uber test vehicle in Tempe, AZ, in March 2018 [69]. AV sensors often have difficulty detecting and predicting the travel paths of nonmotorized roadway users, such as bicyclists and pedestrians, in a dynamic mixed human/vehicle operating environment [178]. A research shows that factors that affect pedestrian behavior include pedestrian demographics, traffic dynamics, street configurations, and environmental conditions [179]. There rises a need for AV detection algorithms to incorporate pedestrian and bicyclist intention in multimodal ODDs [180]. Smart roads equipped with connected sensors and lighting provides a solution by transmitting the intentions and whereabouts of road users [181]. Despite the reliance of AVs on TCDs, there must be redundancies to allow the detection of pedestrians and bicyclists outside the marked areas [182]. In terms of signal control, a solution has been put forward that controls the intersection by providing a flashing, audible beacon for pedestrian and bicycle only phase, indicating vehicles to enter the intersection at a slower speed [183]. Until the 100 percent penetration of AVs occurs, city officials may opt for inexpensive design elements, such as regulatory signs and warning devices, could be retrofitted to replace unconnected hardware in the street environment.

Other suggestions from the literature include conducting surveys and audits of road infrastructure to ensure proper right-of-way for pedestrians [184]. This provides an opportunity to identify areas where AVs may present the greatest risks and benefits. Pin-pointing hotspots for vulnerable road users through third-party data platforms is another solution that can be used for street redesign to incorporate both AVs and conventional vehicles [182]. The impact of AVs on transit services and infrastructure is a less-explored area in the literature. In one of the researches looking into stated-preferences of users, it was found that bicyclists' preference for separated facilities such as buffered bicycle lanes and cycle tracks more than doubles in the presence of driverless vehicles in a variety of hypothetical scenarios [185]. Researchers indicate that AVs perform better on roads with mode separations clearly marked [182]. Hence, mode separation can provide safe operating environments for AVs and confidence to vulnerable road users, thereby reducing disengagements of AVs.

Road users with disabilities are also one of the vulnerable road users for whom the infrastructure redesign needs to be considered. Americans with Disabilities Act (ADA) in 2010 defined ADA-accessible facilities as those complying with the standards set forth in the act. Examples of ADA infrastructure include curb ramps, curb cuts, and slip-resistant surfaces. Presently, it is quite unclear how these infrastructures will be impacted with 100 percent AV penetration. However, it is recommended that a collaboration with disability rights advocates is essential for analyzing AV impacts on multimodal infrastructure [186].

Curb Space

With the advent of ride-sourcing networks such as Lyft, Waymo and grocery, prescription delivery using AVs, the curb space may need attention to determine the impacts on the curbside resources. Curbside resources may need to be provided for passenger pick-up and drop-off, goods delivery, on-street parking, and transit stops. A drop-off revolution is expected to occur with shared AVs and self-parking AVs which may lead to new types of site design, street design, and access management standards [182]. Again, third-party data platforms can be utilized to locate the high-volume ride-sourcing passenger pick-up and drop-off areas and goods delivery areas which in turn will facilitate the efficient redesign and reallocation of curb space [187]. Furthermore, a node-to-node approach rather than a door-to-door approach for pick-up and drop-off provides for mobility hubs to be developed [187]. Mobility hubs provide access to a variety of shared mobility options using clearly marked zones with dedicated curb space, signposts, or flexible medians.

Charging Facilities

It is a common consensus in the literature that on-demand electric AVs could drastically reduce energy emissions by providing a more efficient transportation system that utilizes cleaner energy sources [182]. Not only on-demand networks, but AVs in general are also likely to provide the environmental and efficiency benefits provided that the AVs are powered by electricity. To gauge the requirement of AVs in terms of charging facilities, it may be necessary to turn the attention to currently operating electric vehicles. Table 5 shows the range of some common EVs operating in the roadways. It can be seen that some of the EVs have range as low as 53 miles and as high as 391 miles. When providing for charging facilities, the conservative approach will be to design the charging facility locations based on the lowest range. Figure 17 shows the locations of the charging stations currently active in Wyoming which are mostly in the city areas. One of the key challenges of accommodating AVs, which are also electric vehicles, is to provide charging facilities in the rural highways. Perhaps one solution to this problem can be powering the rest areas with charging facilities.

Table 5 Range of some common Electric Vehicles

Plug-in EV (Model Year)	Range
Nissan Leaf (2016)	107 mi
Chevrolet Volt (2016)	53 mi
Chevrolet Spark EV	82 mi
Chevrolet Bolt EV	238 mi
Hyundai Iconic Electric (2020)	170 mi
Ford Focus Electric (2017)	115 mi
Tesla Model S	348 mi ~ 391 mi
Tesla Model X	305 mi ~ 351 mi
Tesla Model 3	250 mi ~ 322 mi

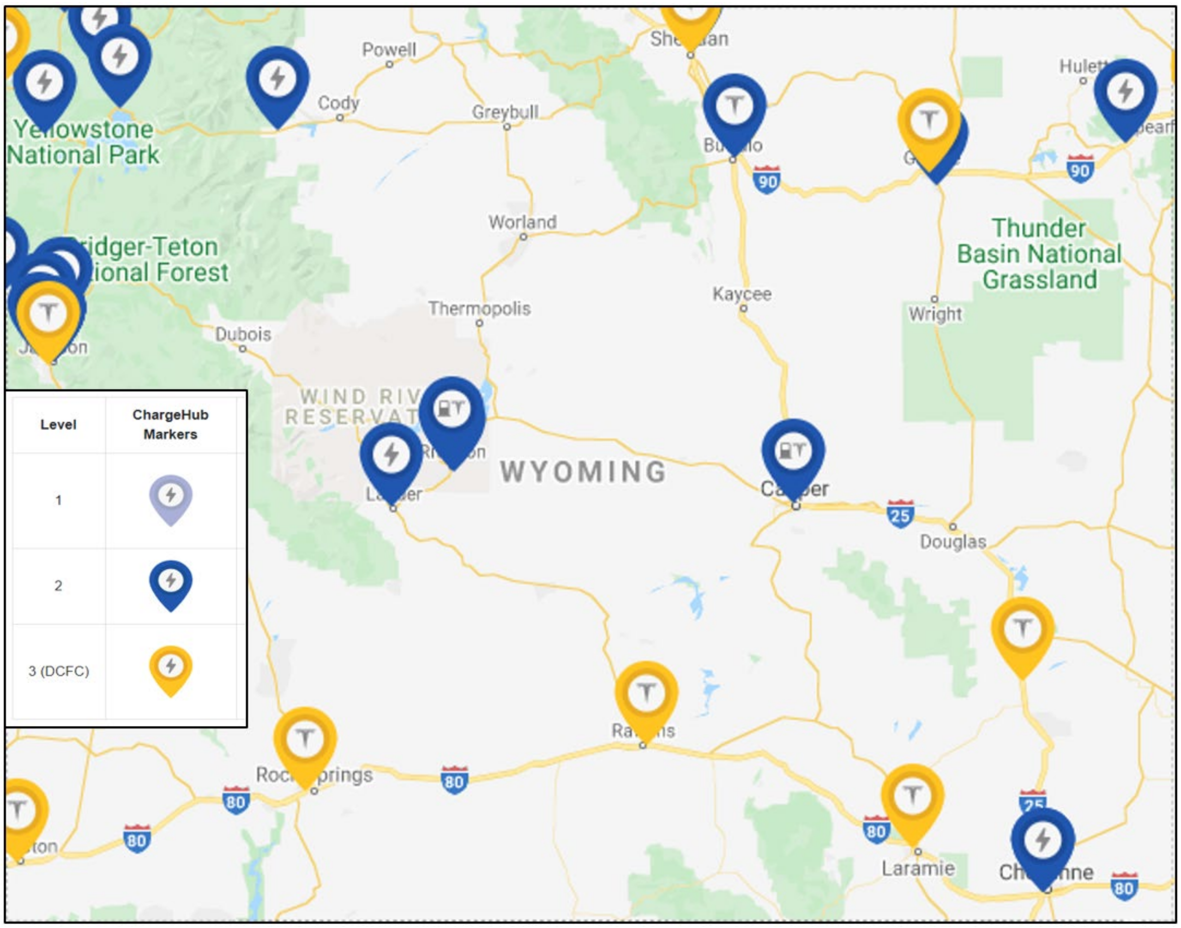


Figure 17 Charging stations in Wyoming. Source: Chargehub.com

There is some research in the literature focusing on developing models to optimally site charging stations [188], [189]. The rationale behind this type of research is the need to consider the potential impacts from autonomous ride-sharing and autonomous vehicles in general.

Although countries and states have the initial charging infrastructure built, as the market share of EVs grows along with AVs, the charging infrastructure will also need to expand accordingly to support the additional charging demands.

Some active on-going research shows that there can be non-intrusive ways of charging, where the vehicle will not have to stop anywhere to charge. This is made possible by the technology known as charging-while-driving. Dynamic charging technology converts road segments into conductive/inductive charging lanes. Utah State University (USU) has constructed an electrified test track, and has demonstrated that in-motion electric vehicles can be effectively and safely charged through dynamic wireless charging [190], [191]. Use of overhead charging cables, as shown in Figure 18, for charging on-the-go has been demonstrated by Siemens with a one-mile, zero-emission eHighway setup in Carson, California [192]. Another type of charging technology has been adopted in Stockholm, Sweden where 1.2 miles of a road segment is equipped with two tracks of rail with recharging capability, as shown in Figure 19.

Figure 18 One-mile, zero-emission eHighway demonstration in Carson, California conducted by Siemens. Source: https://www.greencarcongress.com/2017/11/20171109-siemens.html

Figure 19 Electrified road for charging in Stockholm, Sweden. Source: https://www.theguardian.com/environment/2018/apr/12/worlds-first-electrified-road-for-charging-vehicles-opens-in-sweden

Chapter 4 IMPACTS OF CAT ON WORKFORCE AND ENGINEERING CURRICULUM

Emerging technologies related to autonomous vehicles are evolving in a rapid pace. The used systems vary from simple technologies such as distance sensors to alert drivers that they are about to backup into a fixed object; to light sensors, cameras LIDAR, radars, V2V communication that could fully operate vehicles without human intervention. The effect of such technologies does not only affect the transportation sector but also will significantly affect other fields as well, in which workforce and education will be among the affected sectors. Education does not only mean to educate public with the emerging and disruptive technologies, but also providing undergraduate, graduate students and professionals with the skillsets that prepare them properly to manage challenges that might face them in their future career. With the increased adoption rates for CAT technologies, new job opportunities will be created, other jobs will be eliminated by autonomous driving. Significant impacts might affect taxi, transit, and car rental industries. Additionally, educational curriculums, specifically in engineering schools, should be upgraded to include courses that could prepare graduates to work in AV industries. In this chapter, the scale and timing of these impacts, and evolution of worker skill requirements as well as future engineering curriculum development will be investigated. A brief survey questionnaire is conducted to identify the existing changes of curriculum of civil engineering, mechanical engineering, electrical engineering, computer science, etc.

IMPACT OF CAT ON WORKFORCE

The deployment and acceptance of CAT technologies in the workforce are expected to have an impact on many driving occupations. According to the Bureau of Labor Statistics Office of Employment Projections in 2019, there were an estimated 5.3 million occupations in which driving was one the main duties involved in the job. Many of these jobs have the potential for being threatened or fundamentally changed with the emergence of CAT technologies. As the workforce begins this shift, it is imperative to look ahead to the future to prepare for the changes necessary.

Scale of Impact

It cannot be determined for certain how large a scale of impact to expect from the deployment of cooperative autonomous transportation technologies within the workforce. However, through consultation with leading industry experts and consideration of the current occupations that driving plays an integral part a range of potential impacts can be estimated. [193]. Table 6 provides the most recent numbers from the Bureau of Labor Statistics Office of Employment Projections published in 2020 for the 2019 calendar year. As can be seen, there are an estimated 5.3 million occupations at risk of being replaced or fundamentally changed due to the use of CAT technologies in the workforce.

Table 6 Driving Occupational Employment in 2019. Source: [194]

Category	Occupation	Employment
Motor Vehicle Operators	Ambulance Drivers and Attendants, except EMTs	14,900
	Driver/Sales Workers	487,000
	Heavy and TT Truck Drivers	2,029,900
	Light Truck Drivers	1,018,600
	Bus Drivers, Transit & Intercity	223,400
	Other Passenger Vehicle Drivers	853,300
	Other Motor Vehicle Operators	61,700
Material Moving Workers	Industrial Truck & Tractor Operators	634,700
Total		5,323,500

Based on consultation with industry experts, ranges of potential impacts were agreed upon for the various categories of occupations. These ranges can then be used along with the occupational employment numbers to provide an estimated scale of impact of the deployment of CAT technologies in the workforce as shown below in Table 7.

Table 7: Estimated Impact of CAT Technologies. Source: [195]

Occupation	Employment	Range of Replacement Weights		Range of # Jobs Threatened	
Ambulance Drivers and Attendants, except EMTs	14,900	0.05	0.05	745	745
Heavy and TT Truck Drivers	2,029,900	0.6	0.65	1,217,940	1,319,435
Light Truck Drivers	1,018,600	0.45	0.55	458,370	560,230
Bus Drivers, Transit & Intercity	223,400	0.7	0.75	156,380	167,550
Bus Drivers, School or Special Client*	640,973	0.5	0.5	320,487	320,487
Taxi Drivers & Chauffeurs*	229,430	0.2	0.7	45,886	160,601
Self-Employed Drivers*	461,497	0.2	0.2	92,299	92,299
Total	4,618,700			2,292,107	2,621,347
*Estimated				49.63%	56.76%

Utilizing these estimated ranges shows that the full implementation of autonomous technologies will have a large impact on the current driving workforce affecting around 50-57 percent of the occupations that involve driving as of 2019.

Time of Impact

Acknowledging the potential scale of impact that CAT technologies will have on the current workforce, it is necessary to understand just how quickly these changes may come to be in order to prepare for the upcoming changes to driving occupations. Looking back at past changes that had large effects in employment and job content as well as the current rate of AV development it can be reasonably assumed that the vast majority of the potential deployment of CAT in the workforce will happen within the next three decades until 2050. The largest area of variability in the potential rate of impact is the adoption rate of AVs for trucking. As Figure 20 shows a minor variation when comparing the rates of adoption for cars between two possible adoption scenarios. However, there is a large difference between the two potential trucking adoption scenarios.

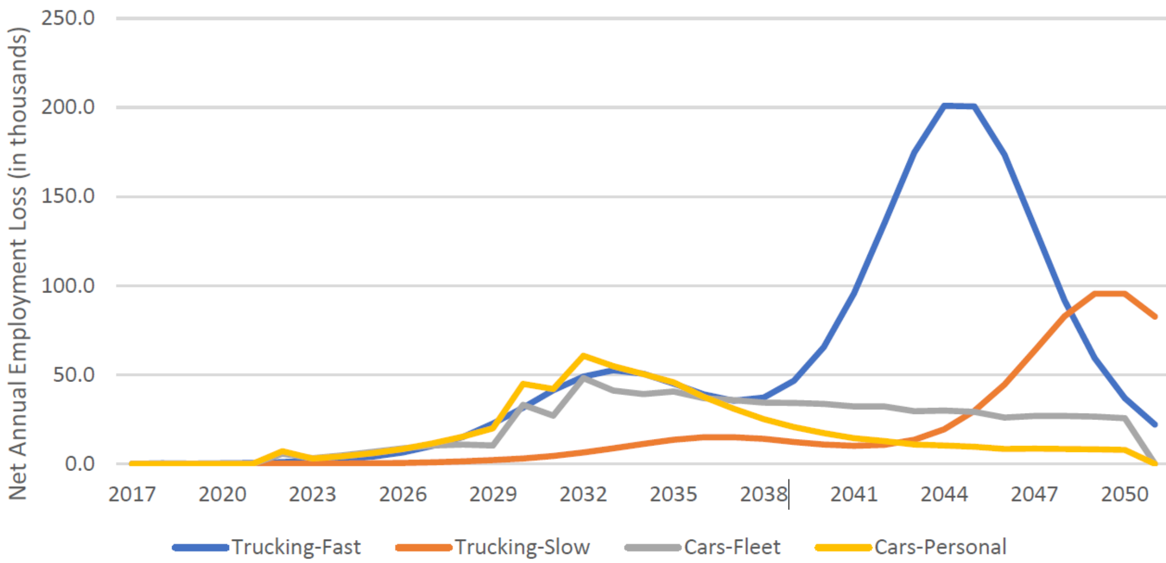


Figure 20: Annual Displacement from AV Adoption. Source: [195]

Fleet adoption of vehicles for transportation service providers is a more aggressive scenario resulting in more rapid adoption of electric vehicles leaving only around 20 percent of the market of AVs being personal, household vehicles with the vast majority being fleet owned. Personal adoption would result in more than just a flip of those results with the market shares of fleet ownership tapering off to only be around 10 percent of the market. The rate of adoption of CAT technologies in the trucking industry will have a much more pronounced effect on the annual worker displacement numbers. The slower option provides a baseline adoption timeline in which it takes roughly 30 years for trucking to adapt to driver-assisted AV before progressing to fully autonomous trucks. This option assumes automation levels of 4 and 5 becoming available in the 2040s and the annual worker displacement tops out just below 100,000 workers per year in the late 2040s. A faster, more aggressive adoption of AV technologies in the trucking industry could have higher levels of automation being implemented as much as a decade earlier than the slow option. This adoption scenario predicts that adoption of automation levels of 4 and 5 with a driver not being required for most trips on most routes would be nearly complete by 2050. This scenario would create a much greater amount of annual displacement in the early 2040s peaking around 200,000 workers per year. Whichever of these scenarios may come to pass, both the trucking and light vehicle scenarios will combine to provide the total scale and timeline of the impact of CAT adoption in the workforce. Figure 21 and Figure 22 provide a visual representation of the estimates of the annual displacement and the overall cumulative displacement of workers through 2050 respectively.

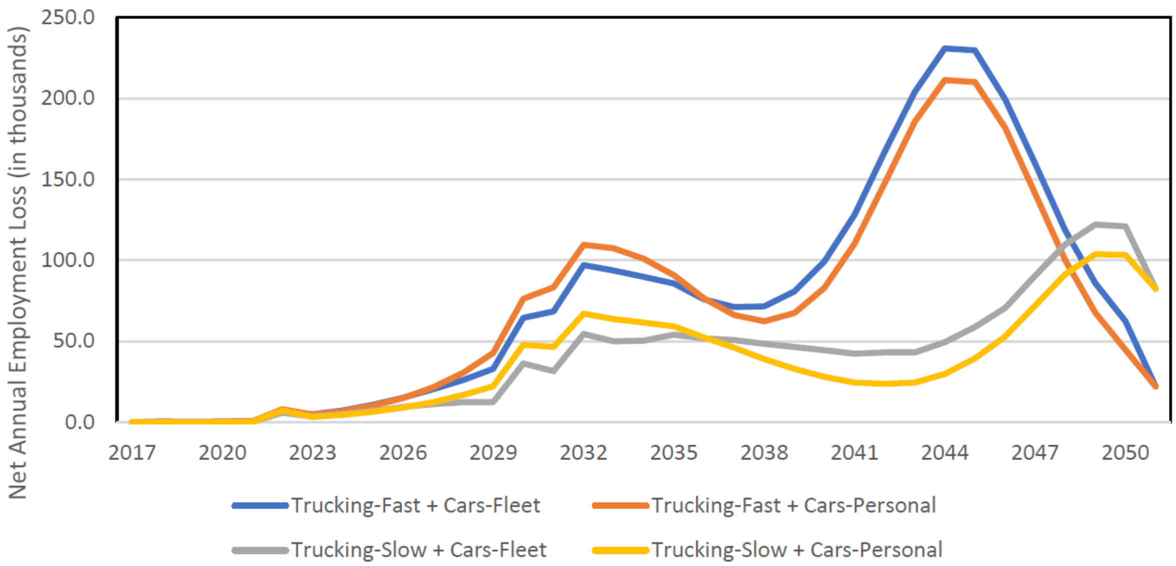


Figure 21: Annual Displacement Rates with Combined Adoption Scenarios. Source: [195]

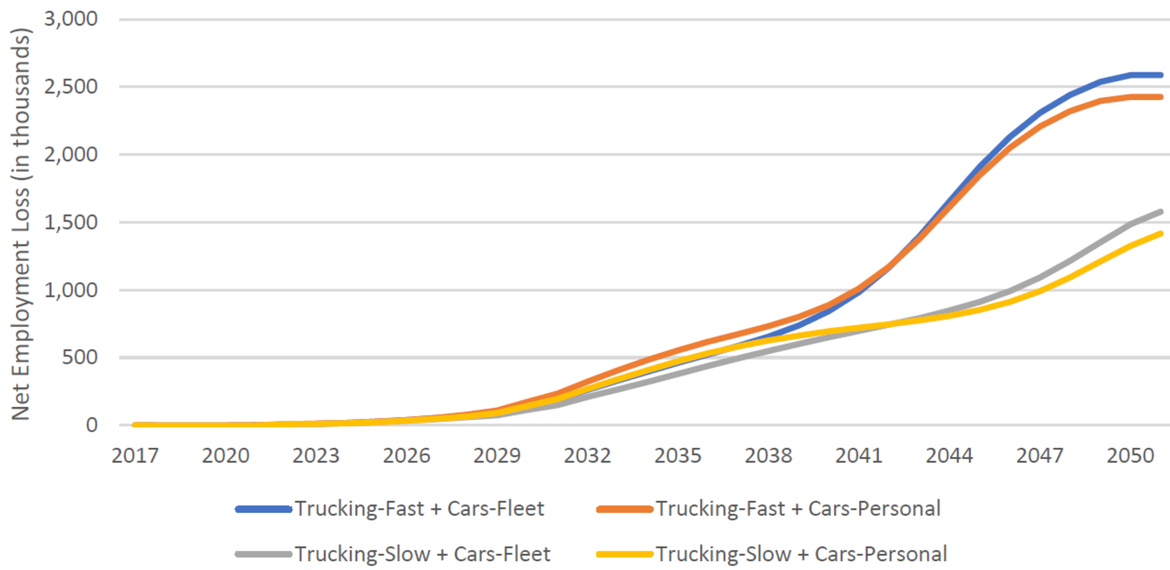


Figure 22: Cumulative Displacement Rates with Combined Adoption Scenarios. Source: [195]

Required Working Skills and Evolution

Although the above scenarios predict such large numbers of job displacement, with an active approach to job replacement and creation the impact on the overall unemployment would be relatively minimal. Figure 23 illustrates the projected differences in job displacement and re-employment comparing the combination of the two higher impact scenarios, fast trucking and fleet adoption of light vehicles, and lower impact combination of slow trucking and personal adoption of light vehicles.

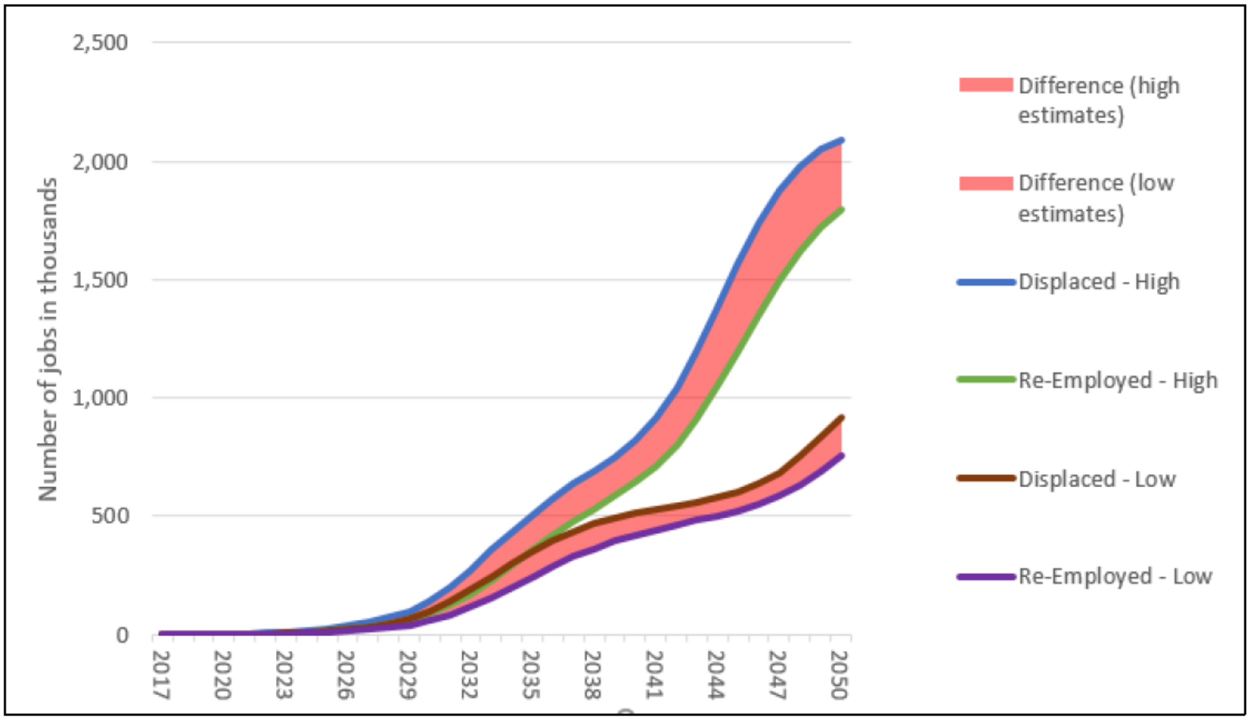


Figure 23: Displacement vs. Re-Employed. Source: [195]

It can be seen above that the rate of re-employment closely follows the rate of unemployment though with a bit of lag time, anywhere from a year or two up to 5 years or so. Job creation lags job displacement as after workers are displaced, some will be unemployed for a period or exit the workforce completely. Additionally, re-employment and job creation is slowed due to their location, rural locations have shown slower job growth than the rest of the U.S., the changing skill sets required for the new positions, the lack of institutions and regulations that value the worker voice leading to insufficient resources being allocated towards retraining and other needed assistance during the transition, and due to a lack of incentives or access to capital for investing in the creation of new jobs. [195] This lag creates a temporary gap, lowering employment while job creation and re-employment catch up. According to the scenarios discussed above, all jobs displaced by CAT deployment will be replaced with new jobs and filled with workers sometime after 2051.

IMPACT OF CAT ON ENGINEERING CURRICULUM

There is no doubt that providing education to public on emerging technologies is important however, educating undergraduates, graduates, and young professional with the required knowledge and skillsets that prepare them to pursue a career and to face challenges with their future career is even more important. The impact of CAT on engineering education cannot be easily quantified as we are still in the early phases of CAT adoption. However, general impact could be synthesized from the impact of disruptive technology on engineering education. Developing new curriculums in existing programs, which provide new graduates with the skills and abilities to deal with emerging technologies, is the main challenge for engineering education. Providing more focus on electrical/electronic systems, sensors, radars, LIDAR, machine vision as well as the algorithms of autonomous vehicles is essential. The emerging CAT technologies will bring opportunities to divisions other than transportation engineering, such as computer science, robotics, and software programming. This will require a broader engineering curriculum to provide comprehensive and inclusive information to prepare student for CAT industry. Another challenge that might be faced is the adaptation pace. CAT technologies adoption is anticipated to be fast, which requires a quick change in engineering education. Nowadays, all modern vehicles are equipped with a sort of disruptive technology, such as light sensors, ultrasonic sensors, cameras, LIDAR, radar, GPS, and live traffic data, to fully drive systems that controls vehicles' speed, acceleration, steering, and brakes.

Transportation engineering curriculum should be reassessed and updated to have relevant and sufficient information that provides their graduates with enabling qualifications to work in CAT industry. Traditional courses for traffic and transportation engineering, i.e., transportation engineering, traffic operations, geometric design, pavement materials, pavement management, and pavement design, are no longer sufficient. With the presence of emerging technologies in transportation, transportation engineers have at least a basic knowledge in areas as machine vision, communication science, computer algorithms, human factor safety engineering, big data analysis, data sciences and programming. In the past recent years, statistics have become an essential topic that transportation professional uses frequently in their career. The massive data obtained from the different transportation systems mandated a solid knowledge with statistics to read, analyze, visualize and understand the performance of such systems. This also upgraded the requirements from attaining the basic and traditional statistic knowledge into acquiring more sophisticated techniques that utilize neural networks and artificial intelligence approaches. The same trend will apply with other science divisions that will help transportation professionals to handle CAT problems. This will make transportation engineering a highly interdisciplinary subject.

Curriculum design and assessment

To design or update a curriculum, the first step is to evaluate the outcomes and to compare them with the industrial and career needs to have an efficient outcome-based education. The skillsets, level of knowledge, and gained capabilities will identify the required course outcome that students expect to attain from completing a specific course. A continuous update for curriculums is important to identify gaps in the course outcomes due to innovative and emerging technologies. Updating academic curriculum with new industry related areas of interest is crucial to have well-prepared graduates. According to the American Society for Engineering Education (ASEE), the Science, Technology, Engineering, and Mathematics (STEM) mobs are expected to increase by nearly 9 percent. The STEM jobs are mainly related to computing, representing nearly 71 percent of total STEM jobs, i.e., software development and Systems Analysts. The U.S. Bureau of Labor Statistics stated that an increase in STEM jobs since 2009 were observed in California, Texas, New York, and Michigan as well as other states, in which the STEM employment growth was about 20 percent compared to national STEM employment growth of 10.5 percent. It is worth mentioning that the states facing an increase in STEM related jobs are considered as leading states in CAT technologies in the US. Figure 24 Shows the Employment change for STEM occupations by state from May 2009 to May 2015.

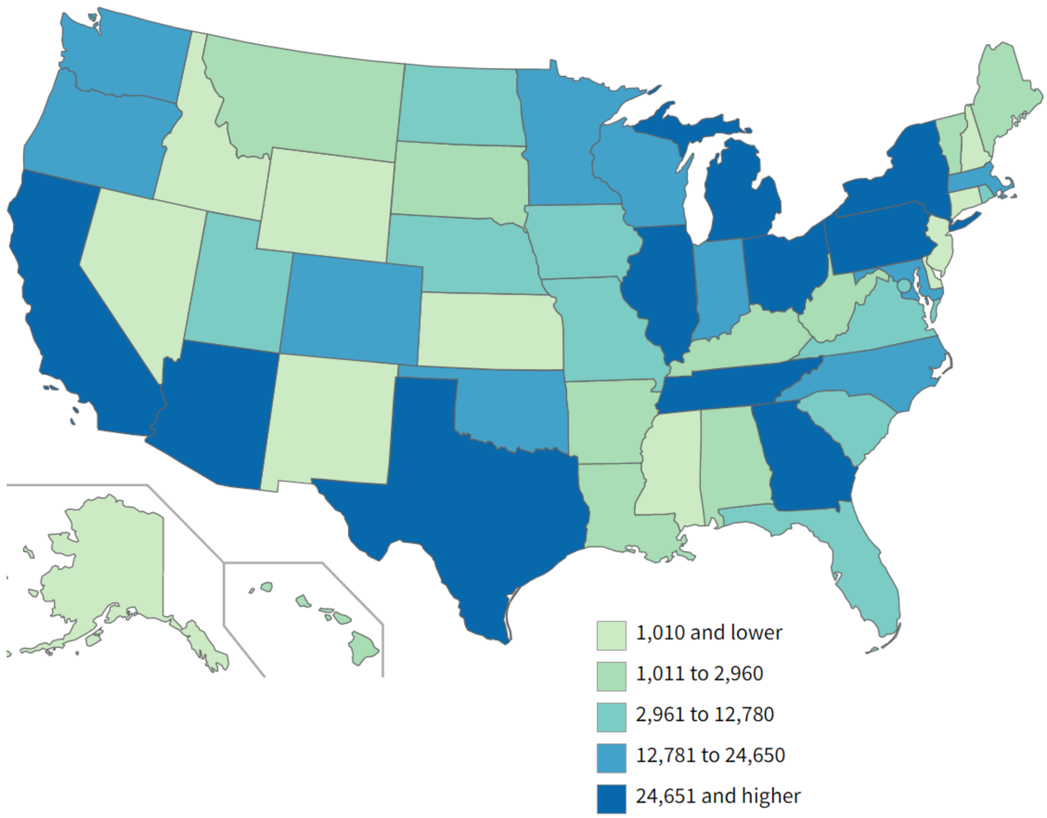


Figure 24 Employment change for STEM occupations by state, May 2009 to May 2015. Source: The US Bureau of Labor Statistics

Open Learning Sources

With rapidly changing industry needs, it is difficult to meet and generate specialized skills requirements with traditional, slowly moving learning systems. It is recommended to pay more attention to dual degree education and training, in which students can choose a major and a minor across a wide range of required skills for industry. This would help to prepare graduates with the relevant skillsets and increase their employability chances. In consultation with industries, educational organizations should identify the curriculum gaps that need development, such as integrating information technology and engineering. Courses in disruptive technologies, i.e., Artificial Intelligence, IoT, Cyber Security, Data Science, Cloud

Technologies, and Augmented Reality, should be provided in academic education to address the trends the industry is taking.

Recently, Massive Open Online Courses (MOOC) are gaining momentum and huge attention by graduates to improve their knowledge and skillsets. Integrating these online learning platforms in the academic curriculum could help in fulfilling the needs for disruptive technology training. MOOC provides an interactive learning approach with instant feedback, where unlimited participation of students from geographically different locations could be achieved (REF). It was reported that in the year 2020a spike was encountered in the number of registered participants for MOOCs (Ref). For example, the total number of registered participants in Coursera, the largest MOOC operator, was 31M in 2020 compared to 8M in 2019 with a total of 76M. Same trends were observed for other MOOC platforms such as edX with 10M participants in 2020 compared to 5M in 2019. This increase in registered participants for the MOOC platforms is related with the pandemic, in which students are accustomed to online learning settings. The massive acceptance for MOOC platforms encouraged several prestigious universities to offer various engineering courses utilizing MOOCs (ref). Several universities award credits from MOOC in their academic programs. The first US University to include credits from MOOC in their programs was Antioch University (ref). Other universities such as Georgia Institute of Technology has a complete MOOC-based degree in computer science (ref). MOOCs overcome several shortcomings in traditional education such as active learning, instant feedback, self-paced and peer learning. However, there are several challenges, i.e., quality assurance, completion rates, academic integrity, and plagiarism that should be dealt with to have reliable MOOC education.

Required New Skills for CAT Jobs

Jobs related to CAT innovative technologies require new skills to be added to the existing set of skills for engineering graduates. The new set of skills could be concluded as programming skills, robotics, and Machine Learning. Connected and autonomous vehicles mainly rely on sensors, LIDAR, Cameras, and radars that are operated using machine vision algorithms and coding. Dealing with both hardware and software to efficiently and safely operate the self-driving vehicles needs advanced knowledge in the aforementioned skillsets. A quick look at leading companies in CAV technologies as GetCruise and Waymo, Software Engineers represent nearly 22-23 percent of the job titles, followed by technical program managers with 3-6 percent. This shows the shift in skillsets needs in transportation related jobs.

Although this dramatic shift in the transportation sector required skills, traditional transportation education is very important. The new required skillsets will only manage to make the vehicles operate and move on our roadways. However, it will not manage to evaluate their performance from an operational and safety perspective. Advanced knowledge with traffic planning, operations, simulations, safety, as well as traditional pavement courses are required to assess the impact of CAT on mobility, operation, safety, environment, and infrastructure.

RECOMMENDATIONS TO POLICYMAKERS, ACADEMIC, AND TECHNICAL INSTITUTES IN WYOMING

Although jobs and occupation will be impacted by the deployment and acceptance of CAT technologies in the workforce, the scale of this impact is still uncertainly determined. However, the scale of the impact was synthesized and estimated by leading industry experts. An initial estimation clarified that nearly 5.3 million occupations could be at risk of being replaced or fundamentally changed due to the use of CAT technologies in the workforce. Most of these jobs are related to drivers in the truck industry, emergency vehicle drivers, bus drivers, and taxi drivers.

An important factor that should be considered is the time and how long would it take to observe this impact. Observing, analyzing, and projecting previous job shifting and impact could provide insights about estimating the expected time to see a shift in jobs and occupations due to CAT. In addition, the current rate of AV development should be accounted for in the impact estimation process. Considering these factors, it can be reasonably assumed that the vast majority of the potential deployment of CAT in the workforce will happen within the next three decades until 2050. It is predicted that the first sector to encounter this impact would be the trucking industry, in which it is estimated that trucks will have the lead in adopting AV technologies. A fast and slow adaptation pace has been suggested for trucking industry. The rate of adoption of CAT technologies in the trucking industry will have a much more pronounced effect on the annual worker displacement numbers. The slower option provides a baseline adoption timeline in which it takes roughly 30 years for trucking to adapt to driver-assisted AV. This option assumes automation levels of 4 and 5 becoming available in the 2040s. A faster, more aggressive adoption of AV technologies in the trucking industry could have higher levels of automation being implemented as much as a decade earlier than the slow option. This adoption scenario predicts that adoption of automation levels of 4 and 5 with a driver not being required for most trips on most routes would be nearly complete by 2050. This scenario would create a much greater amount of annual displacement in the early 2040s.

Moreover, engineering curriculum will be impacted by CAT. The impact of CAT on education cannot be easily quantified as we are still in the early adoption phases of AV technologies. Synthesis of this impact could be done by detecting the impact of disruptive technology on education with a focus on engineering curriculums. There is no doubt that modifications and upgrades should be made in the education sector to prepare graduates for potential future jobs and challenges. Courses that provide knowledge, skills, and abilities to deal with emerging technologies should be incorporated in the engineering curriculum. A reassessment of engineering programs, specifically with transportation engineering, by providing relevant and sufficient information and capabilities to work in CAT industry.

To have an efficient outcome-based education, evaluation of the outcomes is considered the first step. Assessing the needed skillsets, level of knowledge, and required capabilities as well as identifying the gaps in the course outcomes are crucial for the course outcome evaluation process. It is expected to encounter an increase in STEM related jobs of nearly 9, of which most of them are related to computing, software development and Systems Analysts. Open learning sources are considered to provide a shift in the education sector. In the previous years, Massive Open Online Courses (MOOC) gained a huge momentum and attention by graduates to improve their knowledge and skillset. This attacked several universities to have their own MOOC platforms, in which some of them provide a MOOC-based degree.

While this dramatic shift in the transportation sector demands new skill sets, traditional transportation education remains invaluable. The emerging skill sets are essential for operating and maneuvering vehicles on our roadways. However, they may fall short in evaluating vehicle performance from both operational and safety standpoints. Assessing the impact of CAT on mobility, operations, safety, the environment, and infrastructure demands a comprehensive understanding of various fields. Proficiency in traffic planning, operations, simulations, safety, along with traditional pavement courses, is essential to effectively evaluate and address the multifaceted challenges and opportunities brought about by CAT.

As we move towards a future driven by cooperative autonomous transportation technologies it is imperative that we begin to prepare for the upcoming changes to reduce the overall impact on the unemployment rate. Programs should be created and put into place to prepare current employees, as well as new workers, for the shift in job duties and changes in required skills. Incentives should be considered to encourage institutions to create new jobs and provide training for current employees whose jobs may be at risk in order to smooth the upcoming transition. Provided the opportunities and access to training and re-employment, the amount of unemployment added to the current workforce can be mitigated as much as possible.

Electrical engineering and data science and analysts are leading the occupations related to CAT. Although the importance of such occupations, they focus mainly on operating AVs from a mechanical and electrical perspective. When it comes to traffic safety and mobility evaluation, they lack the required set of skills and knowledge to assess the effectiveness of the operating systems. Engineers with transportation background could provide answers regarding how CAT will affect infrastructure, traffic safety, traffic operation, and mobility. Thus, incorporating basic transportation engineering to AV technologies is essential. It is recommended to have more AV oriented transportation and simulation courses for graduate and undergraduate students. Moreover, adding a MOOC platform for the universities would be beneficial. This will allow student to learn at a suitable pace and select specific courses that provide the required knowledge and skills for industrial occupations.

Chapter 5 UPDATED TRANSPORTATION PLANNING MODELS

As much of the future impacts related to the adoption and implementation of AVs still remain uncertain, researchers resort to advanced transportation models such as activity-based models [196], dynamic traffic assignment models [197], and agent-based models [198] to incorporate the impacts of AVs. With the implementation of AVs, it is imperative to include AVs in the planning studies to accommodate the potential impacts of AVs on travel and land use. To this end, for this study of the transportation planning implications of AVs, researchers investigated and synthesized the impacts reported in the literature.

IMPACT OF AUTOMATED DRIVING SYSTEMS ON TRANSPORTATION PLANNING MODELS

Planning studies are carried out to analyze the impact of transportation-related decisions many years into the future and help policymakers allocate resources for developments projects. In the absence of AV performance or impact data, there is reasonable uncertainty surrounding how transportation systems will operate in a future that involves AVs. Despite the limitations, researchers have been studying the impacts of AVs on the four-step process. The four-step transportation planning process is an iterative modeling process and includes separate models for estimating trip generation, trip distribution, mode choice, and route assignment.

While some transportation agencies have already started considering the impacts of AVs on their long-range regional transportation plans, Guerra 2016 explores the extent to which MPOs have actually engaged in these efforts and explains that most MPOs have not considered AVs in their current plans [199]. His work highlights three MPOs that have attempted to quantify the impacts of AVs: the Atlanta Regional Commission (ARC) in Atlanta, GA; the Metropolitan Transportation Commission (MTC) in San Francisco, CA; and the Puget Sound Regional Council (PSRC) in Seattle, WA. The approach used in these three cases was to alter some parameters in existing activity-based models. [200] surveyed multiple planning officials from 120 cities in the U.S. and inspected municipal planning documents of the twenty-five largest U.S. cities. Their results showed that 36 percent of the largest cities mention AV-related policies, revealing that some local governments have begun planning for a future with AVs. However, the cities that mention AV-related policies usually avoid engaging in concrete strategies, instead focusing on the prioritization of “innovation” and “flexibility.” As part of a project funded by the North Central Texas Council of Governments (NCTCOG), we also contacted the New York Metropolitan Transportation Council (NYMTC) to inquire whether and how they have accounted for the potential impacts of AVs in their travel forecasts and found that they are currently not incorporating these effects into their model because AVs are not yet legal in the state, making their future uncertain. While the consideration of AVs in practice is limited, there have been some research-based studies using trip-based modeling, including refining the traditional gravity model to enable lower sensitivity to travel time in the trip distribution step and considering AVs as a distinct mode in the mode choice stage. Some very recent examples include [201], [202], [203], [204], who implement small refinements on a trip-based framework at the statewide and metropolitan scales in Texas, Toronto (Canada), Michigan, Illinois, Virginia, Indiana, South Carolina, and Ontario (Canada). However, these studies typically take a simplified approach when modeling the capacity consumption of AVs, often using a single network-wide factor to adjust link-level capacities, or simply occasionally ignoring capacity impacts altogether. Other research efforts investigate the direct impacts of AVs on capacity [205]. These approaches usually involve developing custom simulation tools to analyze either small highway sections, (such as one road link or one intersection, or small cut-outs of larger networks. In an attempt to more broadly facilitate transportation agencies’ development of a system capable of evaluating the impact of AVs, Mahmassani et al., 2018 worked with the U.S. Department of Transportation on a generalized conceptual framework for an analysis, modeling, and simulation system [206]. The framework they propose, which can be seen in Figure 1, is divided into four main components: supply changes, demand changes, operational performance, and network integration. The authors also developed a prototype of their framework, applying it to a small testbed: the microsimulation of a 3.5-mile section of Interstate 290, in Chicago. Their proposed framework is very broad and is designed to capture all potential changes brought forth by AVs, while maintaining consistency across multiple sub-models. The framework is intended to take advantage of a number of advanced modeling tools, including agent-based simulations, dynamic traffic assignment, and microscopic flow simulations.

The literature overview suggests that transportation agencies and MPOs are interested in incorporating new AV-related transportation elements in their long-term plans but are finding it challenging to do so in the context of their current planning methods. While there are several earlier studies that focus on modeling specific elements of time-use and activity-related impacts of AVs, these studies need to make multiple behavioral assumptions and have to use large-scale resource intensive agent-based simulation approaches. While such activity-based models may provide more accurate forecasts, the uncertainty associated with the model assumptions and the resulting forecasts are at a level where resorting to simpler trip-based models with fewer assumptions, even if less accurate, may be an alternative prudent approach. This approach also has the appeal that it can be readily wrapped around the simpler trip-based modeling approach still used by most MPOs in the country.

Trip Generation

AVs are expected to reduce many of the inconveniences associated with driving. For example, the trouble of finding a parking spot may be delegated to the vehicle itself. Such conveniences will likely make AV-related modes more desirable than other existing modes, leading to more vehicle trips. The repositioning of empty AVs will likely also increase vehicle trips. AVs might also be used to increase transit ridership by facilitating first mile/last mile connectivity [207], [208], [209]. The number of trips by cars may also increase because of existing latent demand: AVs will allow certain demographics (e.g., older adults, individuals under the age of eighteen, and differently abled citizens) to make more trips [18 and 19]. Conversely, access to ICT might reduce the general need for physical travel [20, 21].

Impact of Automated Vehicles on Elderly Population and Disabled

In Nishaka Japan, a small rural community 115 km (71 miles) away from Tokyo, the local government started testing autonomous vehicles in rural areas. The major population in the town is old age people and this service provides essential mobility options to the people in the community at a cheaper price than traditional vehicles [210]. If the shuttle system trials are a success, Japan could see driverless bus systems throughout its rural areas as soon as 2020. The parking lot at Perkins School for the Blind was transformed into a test zone where a golf-cart-like vehicle transported students and staff members, guided by a laptop [211]. Another interesting design concept is having driverless cars for school going kids. Since in the realm of driverless cars integrate school going children in neighborhoods is very important [212]. These examples indicate that even at decentralized and small-scale driverless cars can have a positive impact for providing mobility to groups that traditionally were dependent on others for mobility and travel.

With a growing elderly population, providing access to transportation is one of the greatest societal challenges in the U.S. A feasible solution to this problem is adoption of self-driving vehicles in order to provide safe, convenient, and affordable transportation services to older adults [213]. An online survey approach was adopted to collect data on older adults' travel behavior, transportation needs, and to evaluate three transportation alternatives. The three self-driving transportation alternatives presented were owning a self-driving vehicle, using prepaid taxi services, and getting rides through community services. A total of 173 survey responses were collected from participants aged 60 years or older. Participants, (80 percent or more, responded that they are satisfied with the number of trips they make to stores, medical centers, and to religious and social events. On the other hand, more than one-third of the participants would make more trips than they currently do to visit family and friends and to recreational places if rides were available. Among the three alternatives, prepaid taxi services received the best overall ratings. A majority of the participants also responded that owning a self-driving vehicle was not affordable to them.

Estimating potential increases in travel with autonomous vehicles for the non-driving, elderly and people with travel-restrictive medical conditions [214].

- Light-duty vehicle miles traveled could increase by as much as 14 percent.
- Non-drivers could increase total light-duty vehicle miles traveled by as much as 9 percent.
- Drivers with medical conditions could increase light-duty vehicle miles traveled by as much as 2.6 percent.
- Females could make up most of the increase in vehicle miles traveled.
- Working age adults (ages 19–64) could increase their vehicle miles traveled the most overall in magnitude.

Trip Distribution

It has been speculated that the increased convenience and the possibility of spending time more productively in an autonomous vehicle would make individuals more tolerant of higher in-vehicle travel times [215], [216], [217]. To model this fact, it has been suggested in literature to the reduce value of time (VOT) by some factor when computing mode utilities [218], [219]. It is also likely that AVs' parking convenience might reduce generalized costs between OD pairs.

Mode Choice

The attractiveness of AVs will likely affect mode splits. If AVs obviate the need for parking, AV's mode share should increase, while the share of transit should decrease [220]. Also related to mode choice is the aforementioned reduction in VOT—if time spent inside an AV is perceived as less burdensome than in other modes, it is likely that the share of AVs will increase even further while decreasing that of other modes.

Influence of AVs on Mobility

The possibility of a shift away from personal vehicle ownership toward a shared mobility marketplace. [221].

Shared Mobility

Ridesharing and ride matching a more traditional form of carpooling, with drivers and occupants organizing and sharing a vehicle provided by an employer or a transit authority or using one of the group's private vehicles.

Dynamic ridesharing—using smartphone apps (such as Carma®) or computers to access vehicles and share rides with drivers already on their route to their destination. Dynamic ridesharing can be further sub-classified as:

- Private, informal, dynamic ride sharing, which also can be called slugging, where carpools of riders are formed at formal or informal stations, usually not using computers to link up riders with drivers. These arrangements are most common among users of priced lane systems in order to reduce or eliminate the tolls.
- Commercial TNCs and taxis, where a private company, such as Uber or Lyft, matches paid drivers with riders based on a commonality of destination matched by GPS through a smartphone app. o Autonomous dynamic ridesharing, also called shared autonomous vehicles, is dynamic ridesharing but through the use of driverless vehicles, as envisioned currently. This mode has also been called RoboTaxi and aTaxi (autonomous taxi).

Car sharing, which can be categorized as follows:

- Subscription vehicle services such as Car2Go or ZipCar are similar to vehicle rental but differ in that user (drivers and riders) subscribe to the service and have access to vehicles owned by a private company. Subscribers pay a base fee and a per-trip fee for each use.

- Private car sharing is simply the concept of sharing the ownership and use of a vehicle based on residential and work location and usage patterns. This type of ownership and vehicle sharing may become more popular for older individuals that do not have a daily need for a vehicle and have infrequent trip-making patterns.
- Autonomous car sharing, which is essentially the same as car sharing but with driverless vehicles. If autonomous vehicles become more costly to maintain and use than current autos, this may be a way to reduce the cost of auto ownership to each individual.

An average driver spends 5 percent of a day driving, and the car is parked the other 95 percent of the day [222]. Car- and ridesharing models may reduce this inefficiency by decreasing the amount of time a vehicle is left idle since it is shared among multiple users. An autonomous vehicle that requires no driver could further this system by enabling the car to drive itself between different passengers.

Shared vehicle use could reduce the spontaneity of trip making (the marginal costs of each additional trip are higher and more transparent than for a personal vehicle) and reduce trips made by car in general. Because of the reduced spontaneity caused by a consideration of immediate cost of each trip with shared-ride services, short trips currently made by personal vehicle may shift to walking or biking.

While car sharing is expected to reduce trip making of individuals, autonomous vehicles could counteract this reduction due to the repositioning of driverless cars to optimize pick-ups and drop-offs. On the other hand, if AV/CVs arise in a travel environment that is more multimodal, including ride sharing and bike sharing, then the distribution of travel mode may include less driving alone and more alternative modes overall.

Shared mobility and AV/CVs pose a myriad of complex issues to the planning process.

- As options increase for travelers, agencies responsible for planning will need to have access to additional data that describe the various modes, routes, vehicles, and other options that travelers are choosing.
- Planners will want to know the rationale behind the choices that travelers are making, given the improved information and expanded choice sets presented to each traveler for each trip or tour

Trip Assignment

In theory, AVs' low reaction times and better awareness of their surroundings will likely allow them to utilize road space more efficiently than human drivers. For example, Automated Cruise Control (ACC) and Cooperative Adaptive Cruise Control (CACC) are autonomous-like features that allow vehicles to follow lead vehicles without any human intervention. Studies have shown that vehicles with ACC and CACC can improve traffic safety, stability, and capacity. AVs may also be able to affect network-wide performance by allowing for novel approaches to intersection management [223]. However, it has also been shown that platoons of ACC-enabled vehicles may be prone to large speed variations, and that higher headways (which are more likely at lower AV penetration rates) can cause capacity reductions.

Chapter 6 FACTORS AFFECTING THE ACCEPTANCE OF AVs IN WYOMING

In light of the preliminary literature review, design of a survey questionnaire to collect Wyoming residents' perception of CAT and autonomous driving was conducted (Appendix C). The survey collected demographics such as age, gender, education level, occupation, driving frequency and mileage, driving experience in Wyoming, accident involvement, current autonomous driving technology on their own vehicle(s), and preferences, concerns and willingness to pay for different levels of autonomous driving, including: manual driving (Level 0 automation), partially autonomous driving (Levels 1 and 2 automation), highly autonomous driving (Levels 3 and 4 automation), and fully autonomous driving (Level 5 automation). In addition, the questionnaire measured the conditions under which people would be willing to use CAT, and the secondary tasks that they would be willing to carry out per driving mode. In the instructions, the respondents were informed that they would need approximately 20 to 30 min to complete the survey. The survey primarily focused on Wyoming residents. A total of 1062 responses were utilized in the analysis.

BACKGROUND

Several studies concluded the benefits that could be obtained by having connected and autonomous vehicles (CAV) operating on our roadways. The benefits of CAVs include the reduction of traffic crashes through decision-making and control, traffic environment recognition, path planning, and other means along with reducing traffic congestion and improving fuel efficiency (Kim et al., 2019a). Increased mobility is projected to be one of the biggest advantages with respect to drivers with limited mobility or those who do not have a driver's license due to age or health conditions (Becker & Axhausen, 2017). Additionally, reduced fares for public transportation such as automated buses due to no driver costs were noted as being particularly attractive to the public [226]. However, these benefits, along with a variety of other improvements, will never be realized unless, initially, there is public acceptability of having CAV. It is important to distinguish between the two terms "acceptance" and “acceptability” that might be used interchangeably. Acceptability of a technology refers to the public judgement and evaluation toward a technology before use. While acceptance of a technology is related to the public reactions toward a technology after use. Accordingly, the acceptability online survey introduced in this study could be viewed as a stated-preference survey regarding CAV technology.

As such, when examining the implementation of CAVs, considerations towards the perspectives and opinions of the public must be made. Around the world, surveys have been conducted with respect to user perception of CAVs [227], [228], [229], [230], [231], [232], [233], [234]. Results of these studies indicated that autonomous vehicles were perceived to be a somewhat low risk form of transportation and although concerns existed, there was little opposition to the prospect of the public use of CAVs [226], [233], [234], [235], [236]. However, Wyoming presents a challenging case when it comes to the implementation of autonomous vehicles due to the extreme weather conditions and expansive spacing of towns and cities within the state. Additionally, the mountainous rural nature of the state adds another layer of challenging driving environment. A previously conducted CV Pilot was deployed on Wyoming interstate roads with a focus on improving the safety of commercial vehicles. The CV Pilot included five main CV applications that were identified as category 1: forward collision warning (FCW), category 2: distress notification (DN), category 3: situational awareness (SA), category 4: work zone warnings (WZW), and category 5: spot weather impact warning (SWIW). The driving simulator laboratory at the University of Wyoming was used to assess the effectiveness of the different applications [237]. As a result, it was found that the CV Pilot provided participants with improved road condition information and increased safety while driving [238]. Recently conducted research on available CAV crash data has reported that the predominant majority of CAV involved crashes occur due to human error or misjudgment of the driver operating the conventional vehicle involve [239], [240], [241]. While CAVs have the potential to improve safety and mobility options for all types of people, these improvements are dependent on the acceptability of CAV technology by the general public.

Adoption of autonomous vehicles depends largely on how successful the technology is to attract drivers from regular vehicles. Accordingly, public acceptability has a great importance as the public shapes the demand and the market. Public acceptability could be affected by several aspects including technology reliability, efficiency, safety, security, as well as policies. Public acceptability of CAVs had a large amount of attention from researchers over the last 10 years, in which focus groups and survey questionnaires were utilized. Expert and public opinion was investigated to assess the acceptability of CAVs. Table 8 shows studies that considered public and expert preference about the adoption of CAVs for the last five years. Although several studies highlighted the perceived benefits of CAVs, public adoption highly relies on the public's trust in such technology. Conducting survey studies also indirectly helps in familiarizing the public with expected benefits of CAVs which highlights an additional benefit of this study.

Table 8: Overview of Studies about User Acceptance & Public/Expert Opinion of CAVs

Study Description	Location	Participants	Method	Results	Limitations
A public survey questionnaire to assess public perceptions and acceptance of the two highest levels of vehicle automation. SEM was used to develop a psychological model to explain three acceptance measures namely, general acceptance, behavioral intention to use, and willingness to pay [242].	Tianjin, China	Highly AV (n= 367) and Full AV (n= 375)	SEM	Total of five constructs were obtained (Trust in HAV/FAV, Perceived Benefits, Perceived Risk, General acceptance, Behavioral Intention). The respondents perceived a higher benefit from FAV than from HAV. Non-significant differences were observed in the other constructs. Respondents expressed high concerns regarding safety issues, cyber-security issues, and legal liability issues.	Sample was not completely representative.
A public survey (between-subject) to determine the risk-acceptance rate of varying traffic-risk scenarios using logarithmic regression models. Model results of self-driving vehicles were compared to human driven vehicles models [243].	Tianjin, China	A total of 263 participants for the Highly AV and 271 participants in the Full AV	Logarithmic regression models	Full AV were required to be safer than Highly AV. Results indicated that the respondents had a lower risk-acceptance rate for Full AV than for Highly AV given the same risk frequency.	Ungeneralizable results due to limited sample size. Respondents were not provided information on the potential risks and benefits of Full AV.
An AV acceptance model was proposed by extending the Technology Acceptance Model (TAM) with social and personal factors. The validity of the proposed model was confirmed with a questionnaire survey [244].	China	A total of 604 drivers	Partial Least Squares SEM	The SEM results showed that social influence and initial trust played the most important role in determining whether users intend to use AVs or not.	Results cannot be generalized due to limited sample size. Participants were not familiar with AVs.
Studied user expectations and concerns, as well as their provenance, by conducting a series of online Focus Group (FG) discussions with transport area experts and non-expert participants [245].	Italy, Germany, and Spain	72 people from 15 EU and 8 non-EU countries participated.	Descriptive analysis	Most of participants provided a positive evaluation for CAVs. Participants perceived potential benefits, including safety, accessibility and travel efficiency, participants mentioned concerns regarding safety, legal responsibility, and privacy.	Decreased level of interaction between participants compared to a face-to-face discussion.
Conducted a nuanced examination survey of how attitudes and opinions towards AVs are related to the unique profile of demographic and characteristics of Australian respondents. Descriptive analysis and Spearman Rho correlations were utilized in the analysis phase [246].	Australia	5089 respondents	Descriptive statistics and Spearman Rho correlations	Respondents expressed the highest agreement that AVs would increase mobility for people with driving impairments or restrictions. Several concerns were highlighted including concern with allowing children to ride in an AV by themselves. Crash liability was among the stated concerns.	The cross-sectional nature of the research precludes formulation of any conclusions about causality between the constructs of interest.

Study Description	Location	Participants	Method	Results	Limitations
Understanding public acceptance of autonomous vehicles using the theory of planned behavior. A survey questionnaire is designed to collect information from the public, in which SEM was used for survey analysis [247].	Seoul, Korea	526 residents	SEM	The outcomes show individuals' mindset on AVs, subjective customs, and behavioral influence directly influencing the acceptance of AVs. Cognitive and emotive factors, namely comparative advantage, compatibility, complexity, and hedonic motivation indirectly influence the acceptance of AVs via mindset and behavioral manipulation.	Survey was conducted in a city with a dense population and a high proportion of working professionals possibly in favor of the using AVs.
Examined how attitudes and opinions towards AVs may impact willingness to pay (WTP) for the technology [248].	Australia and New Zealand	6133 Participants	Logistical hierarchical regression analyses	Results showed that attitudes and opinions relating to perceived benefits, level of comfort with an AV undertaking certain driving functions, and engagement in secondary activities were among the strongest predictors of WTP. The weakest were associated with awareness of AV technologies and perceived concerns.	The cross-sectional nature of our research precludes conclusions regarding causality between the variables investigated. The elicitation nature of the study might not reflect the real purchasing behavior and might lead to over- or understating of true valuations.
Compared between the perception of individual and expert toward the benefits and concerns of connected and autonomous vehicles [249].	Korea	98 Individual and 46 experts	Analytic hierarchy process using ANOVA	Safety improvement and driving and parking conveniences were highly recognized by individuals and experts as benefits of CAVs. Reducing insurance rates, taking a break, enjoying entertainment, and doing productive working while driving was perceived as relatively low in both groups.	Sample size was limited and was not completely representative. Study did not address social issues such as job losses for taxi or truck drivers as it mainly considered the benefits or risks on the individual side.
Conducted an international survey questionnaire to collect public opinion on automated vehicles [250].	109 countries	5000 responses	Descriptive statistics and correlations	Respondents were found to be most concerned about software hacking/misuse and were also concerned about legal issues and safety. Respondents from more developed countries (in terms of lower accident statistics, higher education, and higher income) were less comfortable with their vehicle transmitting data.	Small sample size. Results mainly represent advanced countries, as access to low-income counties was limited.

Study Description	Location	Participants	Method	Results	Limitations
Investigated a multi-group analysis of the behavioral intention to ride in autonomous vehicles [251].	Chicago, Indianapolis, and Phoenix	1200 (400 Participants per state)	CFA and SEM	The results of the structural model suggest that the synergistic effects between Theory of Planned Behavior (TPB) and Diffusion of Innovation (DoI) can better explain the behavioral intention to ride in AVs	A portion of the general population that lies within the target population was not reachable. The samples are not representative in terms of education and income. hypothetical nature of surveys about AVs
Explained the differences between people who have ridden a CAV in downtown Las Vegas (shuttle-rider survey) versus those who have not (general survey) [252].	Las Vegas, Nevada	236 for general survey and 153 for shuttle-rider surveys	Penalized Logistic Regression	Higher income participants feel more positively about CAVs while in the shuttle-rider survey, lower income people feel more positively. Participants from both surveys who use ride-hail, work vehicles, or other had low probabilities of anticipating CAVs to have benefits. Few participants who had ridden the shuttle expressed any negative sentiments toward CAVs.	Sample was not completely representative

SURVEY PREPARATION, PROCESSING, AND DESCRIPTION

The survey responses utilized in this study were collected from an Institutional Review Board (IRB) approved online public survey created using Qualtrics and distributed through a variety of methods including Facebook posts in Wyoming based groups and on profile timelines. Additionally, the survey link was distributed using the University of Wyoming's student, faculty, and staff e-mail lists. The survey offered the opportunity to win a $25 Amazon gift card. Due to this, the collected responses were analyzed to detect and remove any invalid responses that were attempted to be entered into the drawing without providing valid responses. Various considerations were made to address the validity of collected responses. Three different dummy questions were added to the survey which were used to identify respondents who were not actually reading the questions by asking them to answer with a specific response. After these responses were removed, along with incomplete surveys, the time it took respondents to complete the survey was considered and analyzed. The predicted duration of the survey according to Qualtrics data was 17.9 minutes and testing by the researchers provided an estimated 15 minutes to complete the survey. The survey responses were then analyzed to determine the distribution of durations and consideration was given to respondents with possible rapid reading ability and response times. Additionally, distractions and interruptions while taking the survey were considered and incorporated into the decision of a time interval limiting the responses to between 5 minutes and 1 hour.

Participants

In total, 2062 responses were collected initially before any data cleansing was performed. After data cleansing, 1062 responses were used in this study, which is more than the required sample size, calculated based on equation (1) [253].

$$Sample\ Size = \frac{\frac{z^2 \times p \times (1-p)}{e^2}}{1 + \left(\frac{z^2 \times p \times (1-p)}{e^2 \times N}\right)} \tag{1}$$

Confidence interval of 99 percent with the corresponding z-score of 2.576 and a 5 percent margin of error (e) were utilized to calculate the sample size. It is challenging to have solid prior information about the population's acceptability of the CAV technologies in advance. Accordingly, the population proportion (p) of a value of 0.5 was used to calculate the optimum sample size, assuming that 50 percent of population are in favor of CAV technologies. The value of (N) represents the population of Wyoming, which is nearly 579,000. Accordingly, the minimum calculated sample size was 663 participants, which was lower than the obtained responses.

Participants of this survey were required to indicate being at least 18 years of age in order to participate. Figure 25 shows various demographic attributes of the included respondents. The majority of the participants were male with 57.34 percent (609 respondents) of the responses while only 35.03 percent (372) responses were indicated as female. Non-Binary/Third Gender, Other, and responses in which the participant preferred not to answer accounted for the remaining 7.62 percent (81) respondents. Most respondents were between 35 and 44 years of age with 46.33 percent (492) of responses, followed closely by those indicating being between 25 and 34 with 39.45 percent (419) of responses. The third largest age category was that of respondents between the ages of 45 and 54 with 8.57 percent (91). The smallest categories comprising the remaining 5.65 percent (60) responses were the age brackets of 18-24 with 2.45 percent (26) of responses, 55-64 with 1.13 percent (12), 65 or older with 0.19 percent (2), and those who preferred not to answer with 1.88 percent (20) of responses. The largest educational category with 33.71 percent (358) of the people surveyed was respondents who indicated receiving at most an associate degree or certificate program. This was closely followed by respondents who had completed a high school degree or equivalent, 30.23 percent (321), and those who had achieved a bachelor's degree, 27.50 percent (292). The remaining three educational categories of having obtained a graduate degree, less than a high school diploma, and other comprised the remaining 8.56 percent (91) of the responses. The vast majority of respondents indicated being currently employed full-time with 73.54 percent (781) responses followed by respondents who are currently employed part-time with 22.79 percent (242) responses. The remaining 3.67 percent (39) responses included people who indicated being a student (24), retired (9), not currently employed (3), and those who preferred not to answer (3). Participants of the survey were also asked about their frequency of out-of-town travel. The three largest categories related to out-of-town travel frequency were those in which respondents indicated travelling out of town 2-3 times per week, once a week, or 2-3 times per month with 27.78 percent (295), 24.58 percent (261), and 26.08 percent (277) responses respectively. The remaining 21.56 percent (229) responses were divided between respondents who travel out of town everyday (119), once a month (56), a few times a year (51), never (2), and those who preferred not to answer (1).

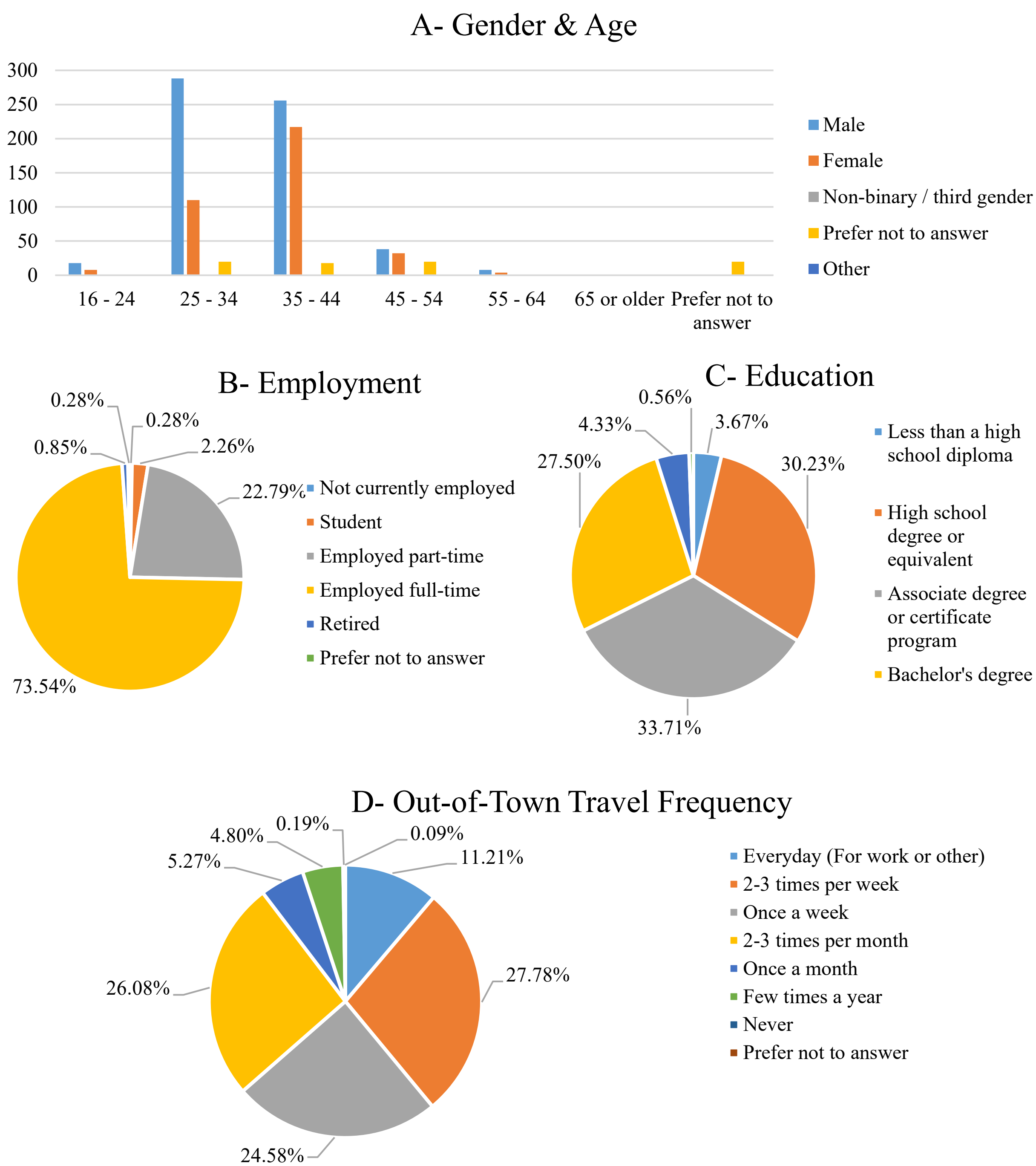


Figure 25: Demographic Attributes

Survey Instrument

One of the initial goals of this survey was to determine the public's overall perception of various CAV technologies. Respondents were queried about their perception of large categories of CAV technologies, their perception on specific anticipated benefits of CAV technologies, and the usefulness of specific types of vehicle automation. The survey instrument was broken into eight sections comprised of a total of 60 questions, not including the questions regarding informed consent and demographic information. These eight sections were categorized as follows:

- Familiarity with CAV Technology (13 questions).
- Infrastructure Upgrade Necessity (13 questions).
- Cooperative Autonomous Transportation/Autonomous Vehicles & Disability (7 questions)
- CAVs in Emergency Medical Services (2 questions).
- Autonomous Snowplows (2 questions).
- Privacy Risk (9 questions).
- Cybersecurity of CAVs (4 questions).
- General Opinions (10 questions).

Responses for the majority of questions were recorded using a sliding Likert scale with values ranging from 1 to 7. Those towards the lower end of the scale represent a stronger negative response to the question or a stronger disagreement with the provided statement. Responses with a value of 4 indicated a neutral or moderate stance on the provided statement or question. The upper end of the scale indicated a positive response or a strong agreement with the provided statement. The specific anticipated benefits of CAV technologies were provided with a statement for the respondent to consider and either agree or disagree with. With the different types of vehicular automation, respondents were asked to rate the perceived usefulness of their anticipated benefits. Respondents provided their ratings regarding the perceived necessity of various infrastructure improvements from needing the least attention to needing the most attention. Their general opinions were queried based on the respondents' level of interest in various CAV technologies.

Descriptive Data Analysis

A variety of CAV related technologies were initially described, and questions were posed to gauge their perceived usefulness by the Wyoming public. Lower values indicated lower levels of perceived helpfulness of the corresponding CAV technologies with values of 1 indicating a perception of being not helpful at all. Responses with a value of 4 meant the corresponding technology was viewed as moderately helpful and responses on the upper end of the scale were indicative of strongly positive perception. Values of 7 corresponded to the respective technology being perceived as extremely helpful. Figure 26 shows the average values of the responses for each different CAV technology that was inquired about.

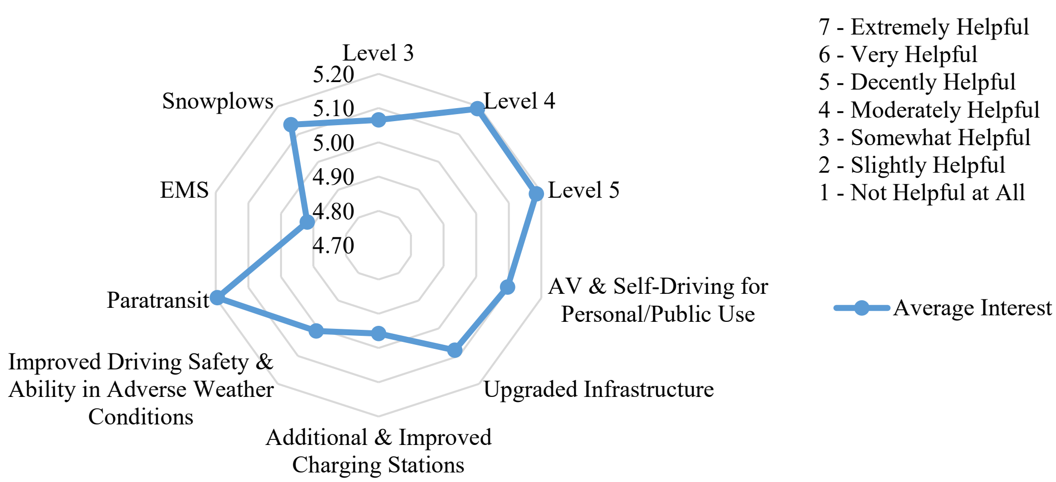


Figure 26: Perceived Usefulness of CAV Technologies

Overall, the average response to all of the different CAV technologies tended to be positive with values greater than 4, indicating them being perceived as at least being moderately or decently helpful. Of the various technologies included in this survey, the three technologies perceived to be the most helpful were 1- the use of CAV technology for Paratransit [self-driving, fixed route ADA (Americans with Disabilities Act) transport service] (average score of 5.20), and both Level 4 and Level 5 automation technologies (score of 5.19 and 5.18, respectively). Level 5 AV technology refers to full automation, in which the vehicle is capable of performing all driving functions under all conditions. While Level 4 AV technology refers to high automation, in which the vehicle is capable of performing all driving functions under certain conditions. The lowest scoring CAV technology was the use of CAV technology for Emergency Medical Services (EMS), such as ambulances, with an average score of 4.92 indicating a moderate to decent helpfulness.

The average responses for the public perception and usefulness of CAV technologies were:

Public Perception:

- Traffic Safety - CAV will help increase traffic safety by reducing crashes (5.249).
- Convenience - CAV features such as automatic parallel parking and adaptive cruise control will improve convenience (5.191).
- Mobility - CAV will help improve accessibility/mobility for passengers with disabilities/limited mobility (5.444).
- Environment - CAV will reduce energy/fuel consumption, lower CO_2 emissions (5.086).
- Amenities - CAV will provide more time doing other tasks during travelling (4.976).

Usefulness of CAV technology

- Cruise control/Adaptive cruise control (maintain preset speed and ensuring safe distance) (5.085).
- Lane keeping assist/Lane departure warning (5.070).
- Automated emergency braking (5.272).
- Traffic jam assist (adaptive cruise control & automated steering at lower speed < 35 mph) (4.956).

- Full vehicle automation (5.300).

Overall, the responses trended positively with average response values for all queried benefits and types of automation being above the median value of 4. Similar to the overall perceived usefulness of CAV technologies, the highest scoring anticipated benefit of autonomous technologies ended up being that of mobility, specifically with respect to improved accessibility and mobility for passengers with disabilities or limited mobility, with an average score of 5.444. Beneficial aspects of CAV technology such as traffic safety and convenience ranked as the next 2 highest scored anticipated benefits with average responses of 5.249 and 5.191, respectively, indicating somewhat to full agreement with the provided statements. The perceived benefit of CAV technologies providing more time for other tasks during travelling had the lowest value, albeit still indicating some agreement of usefulness, with an average response of 4.976. Responses for the perceived usefulness of types of vehicular automation indicated that full vehicle automation (Level 5) had the highest average response of 5.300. This indicates that Level 5 automation is perceived as being decently to very helpful by the respondents of this survey. Automated emergency braking had the second highest rating with an average response of 5.272 followed by cruise control and adaptive cruise control which had an average response of 5.085. The lowest scoring perceived usefulness was that of traffic jam assists with an average response value of 4.956 which still indicates a decently helpful perception.

With the use and level of CAV technologies rapidly progressing, the state of the current infrastructure must be considered with respect to whether upgrades or modifications will be necessary to facilitate the deployment of autonomous vehicles. To this end, respondents were asked to provide their thoughts regarding the needs of the current infrastructure in Wyoming. A 7-level Likert scale was used to collect responses about various aspects of roadway facilities and infrastructure for interstates and highways as well as towns and cities. Responses on the lower end of the scale indicated lower levels of necessary attention with values of 1 indicating the least need. Higher responses indicated greater need of attention with values of 7 indicating the most need. Response values in the middle indicated a moderate necessity. The average responses for each queried facility or type of infrastructure could be concluded as:

Interstates & Highways:

- Upgrade interstate roads with smart road signs (signs that wirelessly send the sign content to the vehicles equipped with CAV technologies) (5.006).
- Upgrade interstate roads with smart pavement marking (pavement marking with micro/nano sensorial system that could be identified in adverse weather conditions) (5.069).
- Upgrade interstate roads with smart merge lanes (5.167).
- Upgrade two-way two-lane highways with smart road signs (5.119).
- Upgrade two-way two-lane highways with smart pavement marking (5.247).
- Upgrade two-way two-lane highways with smart merge lanes (4.899).

Towns & Cities:

- Upgrade with smart technologies for road traffic lights (5.110).
- Upgrade with smart technologies for road signs (5.006).
- Ensure lane markings on city streets are visible and consistent (5.094).
- Enhance intersections by providing more safety treatments (protected left turn phases, refuge islands, etc.) and streetscapes (5.290).
- Upgrade pedestrian accommodations (e.g., crosswalks) (5.047).
- Upgrade parking areas by enhancing snow removal, marking and smart parking (5.128).

The average responses for all queried facilities and types of infrastructure, both for interstates and highways as well as for towns and cities, trended positively. This indicates an average public opinion of there being a necessity for upgrades or modifications of the existing infrastructure in Wyoming to facilitate the deployment of autonomous vehicles. Upgrading two-way two-lane highways with smart pavement markings was identified to have the highest average response of 5.247 indicating a perceived need of the most attention with respect to the infrastructure of Wyoming interstates and highways. The second highest average response was that of upgrading interstate roads with smart merge lanes with a value of 5.167 followed closely by upgrading two-way two-lane highways with smart road signs which had an average response of 5.119. Upgrading two-way two-lane highways with smart merge lanes was indicated to have the lowest response value of 4.899 indicating a slightly more than moderate need of attention. Responses with respect to the roadway facilities and infrastructure of towns and cities identified enhancing intersections by providing more safety treatments and streetscapes to be perceived as needing the most attention by a decent margin with an average response of 5.290. Upgrading parking areas by enhancing snow removal, marking, and smart parking had the second highest average response with a value of 5.128 followed by upgrading road traffic lights with smart technologies with an average response of 5.110. Upgrading the road signs in towns and cities with smart technologies had the lowest average response with a value of 5.006 which still indicates decent necessity of attention.

Another main area of concern with the implementation of connected and autonomous vehicles is that of data privacy and cybersecurity. Connected and automated vehicles (CAVs) are a rich source of data that can be constantly collected by vehicles from the high-quality sensors and cameras embedded in the vehicles. Everything from the local weather data to the quality of the road as well as vehicle dynamics and routes can be gathered and shared with the appropriate parties to enhance the performance and safety of CAVs. However, this level of data collection is an area of concern for many with the potential risk of cyberattacks and data leaks. Respondents were asked a series of questions to gauge their levels of concern with their personal data being exposed to the internet. Figure 27 shows the resulting levels of concern with data privacy of the respondents.

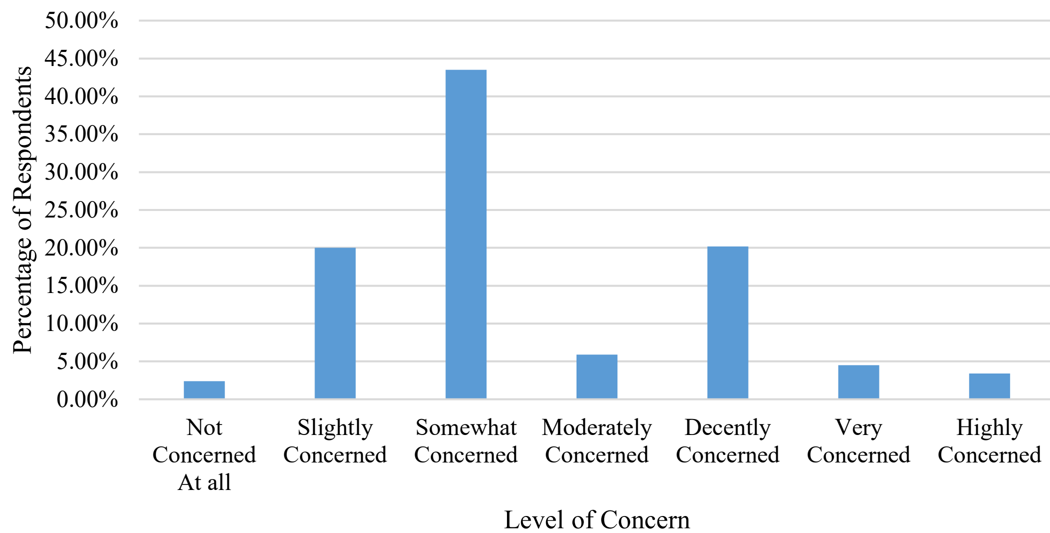


Figure 27: Data Privacy Concern of Respondents

Based on the collected responses, 43.5 percent of the total responses indicated only being somewhat concerned with their personal data being exposed on the internet, while 20.0 percent responded that they were only slightly concerned. Almost 20.2 percent of respondents were decently concerned with their data privacy forming the third highest percentage of respondents. A total of 65.9 percent of respondents reported levels of concern lower than being moderately concerned while only 28.1 percent answered that they were more than just moderately concerned with their data privacy. To further understand the public perception of data exposure risk, responses were then divided based on respondents self-reported average daily electronic device usage. This was done to determine if there was any correlation between the amount of time respondents spent using electronic devices and their level of concern with their private data being exposed on the internet. The distribution of responses is shown in Figure 28.

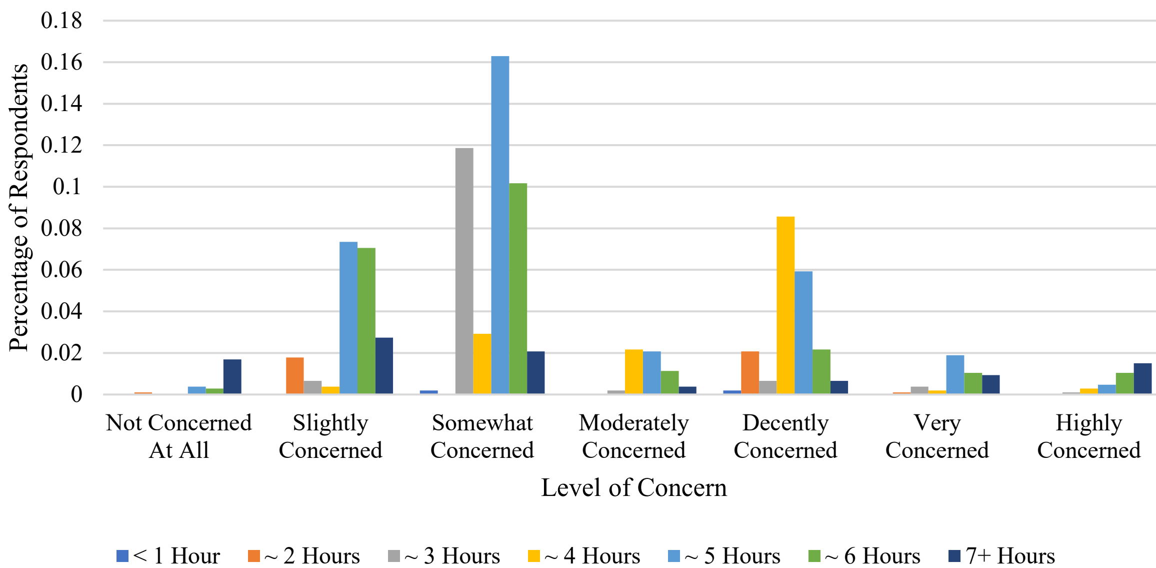


Figure 28: Data Privacy Concern Based on Average Daily Electronic Device Usage

For the majority of categories, based on daily electronic device usage, the level of concern trended on the lower end of the scale. The three largest groups were all respondents who were only somewhat concerned about their data privacy and on average used electronic devices for either around 3, 5, or 6 hours each day. The only category with a notable majority of respondents on the higher end of the scale was that of respondents who reported using their electronic devices for around 4 hours a day on average. Nearly 59.1% of the respondents averaging around 4 hours of daily electronic usage (8.57% of the total respondents) reported being decently concerned with their data privacy.

METHODOLOGY & PRELIMINARY ANALYSIS

Exploratory Factor Analysis

As an initial investigation, Exploratory Factor Analysis (EFA) was adopted to pre-specify the exogenous and endogenous latent variables. EFA was used to uncover the underlying structure of the survey questionnaire, as well as assessing its reliability and validating the survey. It shows to which extent the survey succeeded in quantifying and measuring the factors affecting the public acceptability of CAV technologies. EFA identifies the number of unobserved latent variables (constructs) that produce the variability in the collected/observed survey data. It is worth mentioning that the application of EFA was conducted on a randomly selected 20% of the data observations (213 data observations) to avoid a priori hypothesized patterns when conducting the Confirmatory Factor Analysis (CFA) [254]. The minimum of three indicator variables were selected to measure a single latent variable to avoid convergence issues, in which multiple iterations were conducted to obtain the final factors. The extraction method used to conduct the EFA was the Generalized Least Squares (GLS), with a Varimax orthogonal rotation with a cutoff value of 0.4 for the factor loading values [255]. The obtained Kaiser-Meyer-Olkin value (KMO) was 0.892, indicating well obtained factors [256] [257]. Table 9 shows the factor loadings for the EFA, in which the five obtained constructs succeeded in explaining the main context of the survey and clarified the five underlying factors of the survey.

Table 9: EFA Obtained Latent Variables from the EFA Analysis

Observed Variable	Factor #1 Loading	Factor #2 Loading	Factor #3 Loading	Factor #4 Loading	Factor #5 Loading
Overall Opinion of CAVs	0.580	na	na	na	na
Usefulness of AV Technologies	0.591	na	na	na	na
Overall Wyoming Infrastructure Upgrade Necessity	0.578	na	na	na	na
Increased Efficiency of Using CAV Snowplows	0.529	na	na	na	na
Interest in Level 4 (High Automation) AV Tech	0.654	na	na	na	na
Interest in Level 5 (Full Automation) AV Tech	0.685	na	na	na	na
Interest in CAVs for Personal/Public Use	0.733	na	na	na	na
Interest in Additional & Improved Charging Stations for CAVs	0.695	na	na	na	na
Interest in CAV Paratransit	0.632	na	na	na	na
Concern for Personal Data Collection by CAVs	na	0.685	na	na	na
Preference for Sharing Anonymous Data Only	na	0.560	na	na	na
Frequency of Info Sharing on Social Networking Sites	na	0.535	na	na	na
Promotion of Safety using Cybersecurity Educational Campaigns	na	0.571	na	na	na
Interest in Upgraded Infrastructure for CAVs	na	0.611	na	na	na
Improved Safety Using CAV Snowplows	na	na	0.510	na	na
Improved Safety by Sharing CAV Data with Manufacturers	na	na	0.589	na	na
Manufacturer Liability for Cyberattacks	na	na	0.560	na	na
CAV Owner Liability for Cyberattacks	na	na	0.676	na	na
Concern for Disabled Pedestrians	na	na	na	0.623	na
Willingness to Share Data with CAV Manufacturers	na	na	na	0.531	na
Concern for Cyberattacks on CAVs	na	na	na	0.530	na
Willingness to Use CAV EMS	na	na	na	na	0.573
Perceived Improvement of Using CAV EMS	na	na	na	na	0.653
Interest in CAV EMS	na	na	na	na	0.688

Note: na = not applicable

Confirmatory Factor Analysis (CFA)

Compared to EFA, CFA provides a more parsimonious solution, which generates error variances resulting from the conditional relationship among the indicator variables [258]. CFA was used to determine the measurement models used to conduct the path analysis of the SEM. Absence of multicollinearity was checked by developing a multicollinearity matrix, where the r-squared was less than 0.8 [258] [255]. The selection of the indicator variables should be supported by theory and the results of prior research evidence. Hence, the selected variables were based on the EFA, results of previous studies [259], [260], [261], and engineering judgment. The obtained results from the CFA were nearly similar to the EFA, which was anticipated. The reliability of the indicator variables was assessed based on their contribution to the measurement model. The percent of variance for each indicator that was scrutinized by its latent variable is the index of the item reliability, which is referred to as R^2. The indicator variables with an item reliability index greater than 0.4 are considered ideal [262]. Table 10 shows the obtained values for the item reliability indices (R^2), the latent variables, and the factored indicator variables.

Table 10: Item Reliability Index for the Investigated Indicator Variables

Observed Variable	Factor #1 R^2	Factor #2 R^2	Factor #3 R^2	Factor #4 R^2	Factor #5 R^2
Overall Opinion of CAVs	0.66769	na	na	na	na
Usefulness of CAV Technologies	0.58468	na	na	na	na
Interest in Level 4 (High Automation) AV Tech	0.77388	na	na	na	na
Interest in Level 5 (Full Automation) AV Tech	0.88658	na	na	na	na
Interest in CAVs for Personal/Public Use	0.76872	na	na	na	na
Concern for Personal Data Collection by CAVs	na	0.70301	na	na	na
Preference for Sharing Anonymous Data Only	na	0.99252	na	na	na
Frequency of Info Sharing on Social Networking Sites	na	0.78620	na	na	na
Promotion of Safety using Cybersecurity Educational Campaigns	na	0.79182	na	na	na
Concern for Disabled Pedestrians	na	na	0.50748	na	na
Willingness to Share Data with CAV Manufacturers	na	na	0.91639	na	na
Concern for Cyberattacks on CAVs	na	na	0.63890	na	na
Improved Safety Using CAV Snowplows	na	na	na	0.62393	na
Improved Safety by Sharing CAV Data with Manufacturers	na	na	na	0.82754	na
Manufacturer Liability for Cyberattacks	na	na	na	0.75527	na
CAV Owner Liability for Cyberattacks	na	na	na	1.04719	na
Willingness to Use Autonomous EMS	na	na	na	na	0.75056
Perceived Improvement of Using CAV EMS	na	na	na	na	0.92009
Interest in CAV EMS	na	na	na	na	0.74628

Note: na = not applicable, and R^2=Item Reliability Index

The constructs obtained from the CFA succeeded in further explaining the context of the survey. Five factors were obtained from the CFA:

- Factor 1 is the Public Acceptability of CAVs.
- Factor 2 is the Privacy Concerns.
- Factor 3 is the Public Confidence in CAV Tech.
- Factor 4 is the Operational Liability & Performance.
- Factor 5 is the Acceptability of CAVs in EMS.

The first factor was determined to be the overall public acceptability of CAVs as the observed variables impacting this factor were all questions regarding public interest, perceived usefulness, and overall opinions of CAVs. The observed variables for the second factor, privacy concerns, shared a basis in the public's perceived privacy with respect to their personal information. Increasing values of the variables regarding Concern for personal data collection by CAVs and preference for sharing anonymous data only indicate higher concern for personal data privacy and greater preference towards sharing data without personally identifiable information. Increasing frequency of information sharing on social networking sites was considered to indicate greater willingness to share information for the benefit of others. The last observed variable impacting privacy concerns is the perceived helpfulness of using education campaigns about cybersecurity to increase public awareness of personal data privacy. Public confidence in CAV technology is the third construct that resulted from the CFA. Increasing values for concern for disabled pedestrians correspond to increasing confidence in CAV technology and lower levels of concern for disabled pedestrians with respect to autonomous vehicles operating on the roadway. Larger response values for the observed variable of concern for cyberattacks on CAVs indicated greater agreement that cyberattacks on CAVs are only a minor concern which corresponds to more confidence in CAV Technology. Observed variables influencing operational liability and performance were those regarding the burden of liability with respect to cyberattacks on CAVs in addition to the improvement of safety through sharing CAV data with manufacturers and through the use of CAV snowplows. The final factor was determined to be acceptability of CAVs in EMS with the observed variables being the public interest in, willingness to use, and perceived improvement of using CAV EMS such as self-driving ambulances.

Structural Equation Model

A structural equation model (SEM) is mainly used as a statistical technique to analyze survey questionnaire datasets (Brown, 2015; H. M. Hassan & Abdel-Aty, 2013; Hurley et al., 1997; Shaaban et al., 2018). SEM has several advantages as it can handle complex relationships (indirect, multiple, and reverse relationships) between exogenous and endogenous variables [267]. It quantifies unmeasurable variables by developing latent variables using the observed variables. Moreover, it simultaneously estimates the path coefficients of the relationships between the latent variables in the context of a full model.

Model Development

SEM could be defined as a multivariate statistical analysis that analyze structural relationships between the measurement model and latent constructs, in which endogenous and exogenous variables are analyzed [268]. The SEM assumes a directional relationship between the developed latent variables resulting from the CFA. The SEM consists of two major components; 1) The measurement model, which specifies the significant variables that can measure each constructed latent variable with an exogenous model (x-measurement model) and an endogenous model (y-measurement model), and 2) The structural model, which specifies the significant direction of prediction between the exogenous model and the endogenous model.

The measurement model is basically developed in the CFA phase. In the structural model, simultaneous equations are formed by linking the exogenous and endogenous variables [269]. To avoid identification and convergence issues, a minimum number of three indicator variables should measure each developed latent variable [270]. Additionally, it is advised to use a maximum of 30 indicator variables to obtain a converged model and to evade model fitting issues [262].

It is worth mentioning that the estimation method used to develop the SEM was the Diagonal Weighted Least Square (DWLS) method. DWLS method does not have a specific distributional assumption toward the data [271], [272]. Among the other estimation methods, DWLS was designed to deal specifically with ordinal data. Several studies investigated the validity of using the DWLS estimation method with ordinal data and found that it led to unbiased results [273], [274], [275], [276].

The sample size is one of the important factors to develop SEM, as it is based on the large sample theory [262]. Various studies had asserted the required minimum sample size to conduct a SEM. A study showed that a minimum of 300 observations is required to develop the SEM [262]. However, other studies showed that a minimum sample size of 200 would be adequate to meet the assumptions of the large sample theory [262]. Another study showed that a ratio of 10:1 for the number of observations to the number of investigated indicator variable should be achieved to obtain an adequate sample size [277]. To measure the adequacy of the sample size used in the analysis, it was suggested to assess the statistical power of the developed SEM [262]. To determine the statistical fit of the model, the confidence intervals surrounding the Root Mean Square Error of Approximation (RMSEA) should be evaluated as well as the RMSEA value. A RMSEA value less than or equal 0.08 suggests adequate statistical power. Figure 29 shows the structure map and the different elements of the SEM. The measurement models could be expressed as shown in equation (2) and the structural model is given in equation (3) [278], [279].

$$\begin{bmatrix} y \\ x \end{bmatrix} = \begin{bmatrix} \lambda_y & 0 \\ 0 & \lambda_x \end{bmatrix} \begin{bmatrix} \eta \\ \xi \end{bmatrix} + \begin{bmatrix} \varepsilon \\ \delta \end{bmatrix} \quad \textbf{(2)}$$

$$\eta = \beta\,\eta + \Gamma\xi + \zeta \quad \textbf{(3)}$$

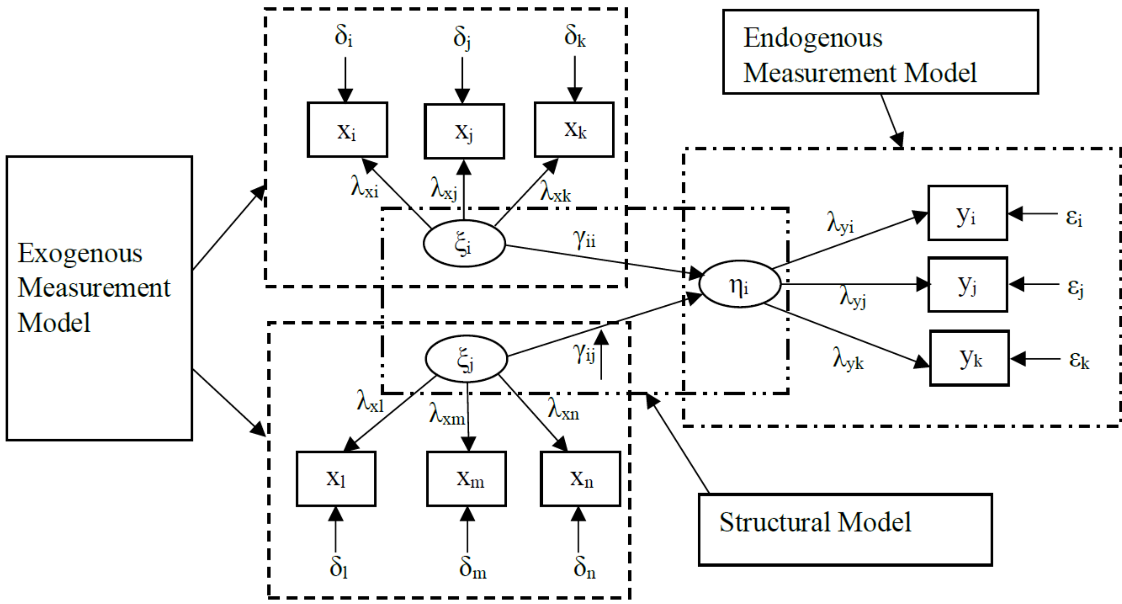


Figure 29: Structural Map and the Elements of the SEM

Where x is the vector of observed exogenous variables, y vector of observed exogenous variables, ξ is the vector of latent exogenous variables, η is the vector of latent endogenous variables, δ is the vector of measurement error terms for observed variables x, ε is the vector of measurement error terms for observed variables y, λ_x is the structural coefficients for latent exogenous variables to the observed variables, λ_y is the structural coefficients for latent endogenous variables to the observed variables, γ regression effects for exogenous latent variables to endogenous latent variables, and δ and ε are the error terms.

RESULTS

Multiple iterations were conducted to obtain the best fit path model based on the goodness of fit indices. Figure 30 shows the developed path model that clarifies the public acceptability of CAV technologies. The latent variables are presented with oval shapes, rectangular shapes represent the indicator variables, and the arrows represent the direction of the model. Path coefficients (estimate) are provided on the top of the path arrows. The obtained standard error and the significance level presented in the form of the t-value are provided below the path arrow. The latent variable representing the public acceptability of CAV, which is explained by five indicator variables, was considered as the endogenous variable. Several direct and indirect relationships were found to be significant in the developed models. Direct relationship occurs when the exogenous variable is directly connected to the endogenous latent variable (i.e., the latent variable privacy concerns is directly connected to the latent variable public acceptability of CAVs). Likewise, the indirect relationship occurs when the exogenous latent variable is connected to the endogenous latent variable through an intermediate exogenous latent variable (i.e., the latent variable Operational Liability & Performance is indirectly connected to the latent variable Public Acceptability of CAVs). The provided path coefficients demonstrate the standardized estimates for the linear equations, in which all the provided coefficients were significant at 95% confidence level. The same approach could be unitized to interpret the developed measurement models.

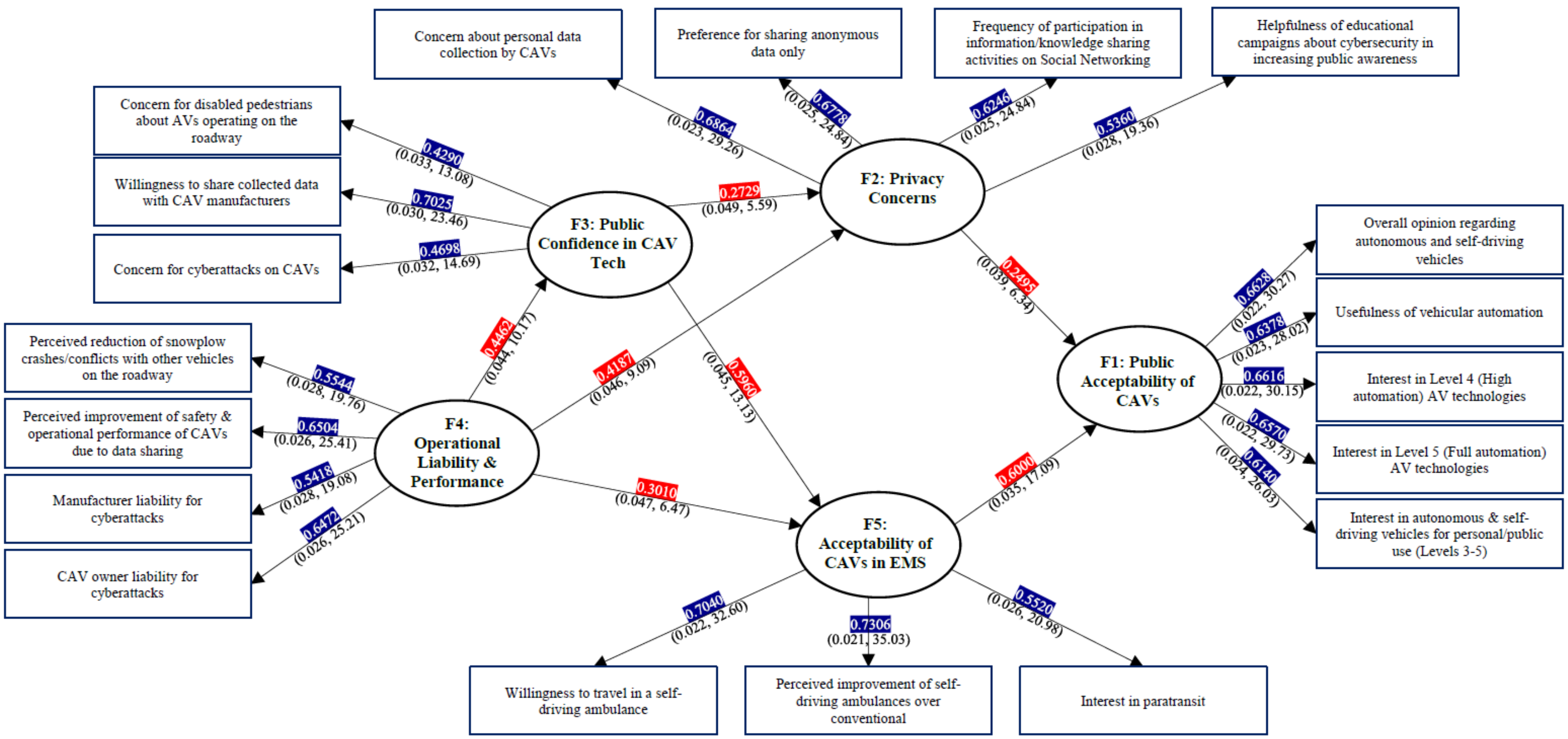


Figure 30: Structural Equation Model (Path Model) for the Public Acceptability of CAV Technology

Results of the Measurement Models

A minimum of three indicator variables were used to express the developed latent variables. The endogenous latent variable expressing the public acceptability of CAV was explained by five indicator variables, in which all the estimates were positive. This measurement model shows that for each unit increase in perceived usefulness of vehicular automation as an indicator variable, the Public Acceptability of CAVs will increase by 0.6378 units. Likewise, for each unit increase in the overall opinion in autonomous and self-driving vehicles, an increase of 0.6628 units will be encountered in the public acceptability of CAVs.

Preference for sharing anonymous data was found to have the highest effect on the second measurement model that describes the public's concern with their personal data privacy. One unit increase in the preference for sharing anonymous data was found to increase the public perception of privacy concerns by 0.6864 units. It was also found that public confidence in CAV Technology was highly affected by the willingness to share collected data with CAV manufacturers. One unit increase in willingness to share collected data with CAV manufacturers would increase the overall public confidence in CAV technology by 0.7025 units. The perceived improvement of safety and operational performance of CAVs due to data sharing was found to be the most significant indicator affecting the fourth latent variable that explains the operational liability and performance of CAV. The results showed that one unit increase in the perceived improvement of safety and operational performance of CAVs due to data sharing will increase the operational liability and performance of CAV by 0.6504 units. The results of the fifth and final measurement model show that one unit increase in perceived improvement of self-driving ambulances over conventional ones will increase the Acceptability of CAVs in EMS by 0.7306 units.

Results of the Structural Model

To interpret the path model shown in Figure 30, the endogenous latent variable of public acceptability of CAVs is the dependent variable as all arrows in the path model end pointing towards it. There are two mediating latent variables which have direct relationships with the dependent variable. The latent variable representing the public privacy concern with respect to their personal data was found to have a direct effect on public acceptability of CAVs. The coefficient for this latent variable indicates that for each unit increase in the public perception of personal data privacy there is a resulting 0.2495 increase in the public acceptability of CAVs. Increasing values of this latent variable represent increasing serenity surrounding the disposition of the public towards the privacy of their personal data due to the associated indicator variables being addressed. The other mediating latent variable shown to have a direct relationship with the public acceptability of CAVs is the acceptability of CAVs in EMS. The coefficient of this relationship is the greatest of the entire path model indicating for each unit increase in the acceptability of CAVs in EMS, there will be an increase of 0.6000 in the public acceptability of CAVs. Public confidence in CAV technology is the third mediating latent variable in the path model having direct relationships with both privacy concerns and acceptability of CAVs in EMS, and an indirect relationship with the public acceptability of CAVs through these other two latent variables. The direct relationships between public confidence in CAV technology and both privacy concerns and acceptability of CAVs in EMS have respective coefficients of 0.2729 and 0.5960. These indicate that for each unit increase in public confidence in CAV technology there will be a resulting increase of 0.2729 in privacy concerns and an increase of 0.5960 in the acceptability of CAVs in EMS. The latter being the second largest path coefficient in the path model. Finally, the exogenous variable regarding operational liability and performance of CAVs is shown to have direct relationships with each of the three mediating latent variables of public confidence in CAV technology, privacy concerns, and acceptability of CAVs in EMS. Additionally, it has indirect relationships with privacy concerns through public confidence in CAVs as well as with the dependent variable of the overall public acceptability of CAVs through all three of the mediating latent variables described previously. The path coefficients show that for each unit increase in the perceived operational liability and performance of CAVs there will be resulting increases of 0.4462 in public confidence in CAV technology, 0.4187 in privacy concerns, and 0.3010 in acceptability of CAVs in EMS.

Goodness of Fit and Statistical Power

Several indices were investigated to assess the adequacy of the developed model. Threshold guidelines provided by [280]   are considered the assessment golden rules for SEM validity [280]. Table 11 concluded the obtained model fit indices and the threshold for each index. Several path models were developed, however, the model with the lowest Akaike Information Criterion (AIC) was reported in this study.

Table 11: Model Fit Indices and Statistical Power Summary for the SEM of CAV Public Acceptability

Model Fit Index	Obtained Values of indices	Threshold Values
Standardized Root Mean Square Residual (SRMR)	0.0484	< 0.050
Goodness of Fit Index (GFI)	0.8814	> 0.900
Parsimony Index - Adjusted GFI (AGFI)	0.8976	> 0.900
RMSEA Estimate	0.05201	< 0.055
Bentler Comparative Fit Index (CFI)	0.9044	> 0.900
Akaike Information Criterion (AIC)	2297	Lower is better

While a couple of the obtained model fit indices did not meet their respective threshold minimum limits and the model fit for the developed models provides an acceptable fit given the minor variation from the limits. The obtained GFI and AGFI values were just below the threshold limit of 0.900 for each of them with values of 0.8814 and 0.8976, respectively. All other indices were within the threshold ranges indicated. The RMSEA value can be used to measure the statistical power of the model, which can be seen in Table 11 as being below the threshold value indicating adequate statistical power.

CONCLUSIONS OF THE CAV SURVEY

This survey analysis aimed to offer reliable information to assist governments, vehicle manufacturers, and stakeholders in the safe testing and deployment of connected and autonomous vehicles (CAVs). As the era of automated driving systems approaches, the public's acceptance of CAVs in Wyoming becomes a crucial factor for consideration when deploying these vehicles on public roads. The analysis in this study lays the groundwork for understanding the driving factors influencing public acceptance of CAVs in Wyoming. The study found that self-driving, fixed-route, curb-to-curb paratransit services were not only the aspects of CAV technology generating the most public interest but also the most influential latent variable affecting public acceptability, as indicated by the SEM path model. This aligns with the highest-rated anticipated benefit of CAV technologies, which is improved mobility. The study also highlighted Levels 4 and 5 of vehicular automation (high automation and full automation, respectively) as significant areas of public interest. Full vehicular automation, Level 5, was perceived as the most useful among various Advanced Driver Assistance Systems (ADAS), closely followed by automated emergency braking. Consequently, the recommendation is to prioritize testing and deploying CAV technologies in emergency management and paratransit sectors to address the identified areas of public interest and maximize perceived usefulness.

Among the surveyed infrastructure needs, the public expressed a strong preference for prioritizing the improvement of two-way, two-lane highways through the integration of smart pavement markings. Additionally, there was a notable emphasis on enhancing intersections in towns and cities by implementing additional safety treatments. The overarching goal is to advance safety measures on highways by incorporating intelligent transportation systems (ITS)-related roadway treatments and countermeasures. Specifically, upgrading highway markings and signs offers a dual benefit: firstly, it enhances visibility for regular road users, contributing to a potential reduction in the frequency and severity of accidents. Secondly, it addresses the requirements of CAV technologies, enabling them to better sense their surroundings and consequently improving their performance on rural roads.

Responses to inquiries regarding data privacy revealed that, on average, the level of concern ranged from slight to moderate. Overall, public perceptions of autonomous and self-driving vehicles demonstrated a positive trend across all categories in the average responses. The

Structural Equation Model (SEM) path model, derived from Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA), indicated that the public's acceptance of CAVs was most directly influenced by their acceptance of CAVs in Emergency Medical Services (EMS) and concerns about privacy regarding personal data. This acceptance was indirectly affected by public confidence in CAV technology, as well as considerations related to the operational liability and performance of CAVs. To address these findings, it is recommended to conduct campaigns that educate the public about the safety and security of their information. Additionally, a crucial priority is the development of robust security architectures and intrusion detection systems capable of detecting and preventing cyberattacks, ensuring the successful deployment of CAVs. Furthermore, public concerns regarding liability issues for CAVs, particularly in the event of a crash involving a Level 5 Autonomous Vehicle (AV), suggest a need to shift liability away from the driver, aligning with recent research findings [281].

The survey results from the public indicate a notable interest in and increased acceptance of CAV technology, particularly in its perceived ability to drive more safely than human drivers, especially in challenging weather conditions. To enhance the safety of CAVs in adverse weather, it is recommended to conduct pilot testing specifically on rural roadways, where such conditions are prevalent. This approach could significantly contribute to fostering greater public acceptance, particularly in regions like Wyoming. Moreover, considering live demonstrations of the technology through various media channels or driving simulations could be beneficial. These demonstrations have the potential to boost people's trust in CAV safety and positively shape their perceptions of this emerging technology [282].

Chapter 7 SAFETY APPROACH OF THE MANUFACTURERS

The USDOT through the NHTSA developed a Voluntary Guidance to support the automotive industry, the states, and other key stakeholders in testing and deployment of autonomous vehicle technologies [6]. Based on the research conducted by the TRB, universities, and the NHTSA, the guidance provides 12 priority safety design elements. Autonomous vehicle manufacturers are encouraged to consider the safety elements in the design of their systems. It is also expected that the manufacturers document their process for assessment, testing, and validation of the various elements. The guidance is completely voluntary and there is no single standard yet to measure a manufacturer's methods of compliance to the safety elements. However, NHTSA expects the industry to be creative and innovative in developing the best method for mitigating the safety risks associated with their approach. As a result, each entity involved in the manufacturing, testing, and deployment of autonomous vehicles address these safety elements in their own unique ways. The following sections summarize and describe the approaches adopted by the different entities.

NHTSA SAFETY ELEMENTS AND THEIR IMPLEMENTATION BY THE INDUSTRY ENTITIES

The 12 safety elements outlined by the NHTSA and how the industry manufacturers incorporate these elements into their design, testing, and deployment are summarized in Table 12 through Table 23. The NHTSA does not enforce the implementation of these safety elements. Thus, the information provided in Table 12 to Table 23 are obtained from the entities' reports which are publicly accessible.

Table 12: System Safety (1/12) – Systems-engineering approach incorporated into the design and validation methods to minimize risks.

Entity	Approach / Description
WAYMO (GOOGLE)	• Safety by Design: safety from the ground up and incorporate safety at every system level and every development stage, from design to testing and validation. It is a multi-pronged approach that builds upon best practices from a variety of industries, including aerospace, automotive, and defense (including aspects of MIL-STD-882E and ISO 26262).
ARGO AI (FORD)	• At every stage of design and testing, Ford's engineers use systems engineering tools and processes and supplement them with lessons from the aerospace industry's long history of automation and safety. • Ford's functional safety process is strongly aligned with the industry automotive safety standard (ISO 26262). Integration of hazard analysis techniques, such as Systems-Theoretic Process Analysis (STPA), along with aspects of the Safety of the Intended Functionality (SOTIF) draft Standard.
CRUISE (GM)	• Designing a capable system and thoroughly analyzing safety performance • Using the right engineering tools • Applying the development processes to the self-driving vehicle • Manufacturing supports system safety • System safety through city testing and proving safe driving through experience
BMW iNEXT	• The international ISO standards for functional safety (ISO 26262) and safety of the intended function (ISO/PAS 21448) as well as other robust internal BMW processes are followed. Functional safety process facilitates hazard analysis and safety risk assessment attributed by Automotive Safety Integrity Level (ASIL). For highly safety relevant functions, specific redundancies have been built in so that failures of these systems do not create an unreasonable safety risk.
APPLE	• The ADS design and integration into the test vehicle is analyzed using various industry safety analysis methods and best practices. The analyses begin during the development process to identify potential hazards so that the design can be easily changed to prevent or reduce the identified hazards. • The hazard analysis is focused on the planned use case of the test vehicles (including driving maneuvers, objects, and events expected to be encountered on the road) and the fact that a safety driver will always be present. • Any malfunctions and scenarios that require the safety driver to take control of the vehicle to address a hazard are further studied to confirm that the safety driver could regain manual control of the vehicle safely. This includes simulations and vehicle testing with induced faults at proving grounds.
UBER ATG	• Uber Advanced Technologies Group (ATG) developed a Safety Case Framework for the responsible development and deployment of self-driving vehicles. The framework includes five Safety Principles – Proficient, Fail-Safe, Continuously Improving, Resilient, and Trustworthy.
LYFT	• Lyft incorporates applicable principles and processes from existing industry standards and best practices, such as AVSC, SAE, ISO 26262, ISO 21448, as well as others. • Lyft carries out hazard analysis and mitigation by using novel processes alongside established tools and processes, such as hazard and risk analysis (HARA), fault tree analysis (FTA), and failure mode and effect analysis (FMEA).

Table 13 Operational Design Domain (ODD) (2/12) – Refers to the environment, including location, weather and speeds, in which the self-driving vehicle is designed to operate.

Entity	Approach / Description
WAYMO (GOOGLE)	• Waymo's domain includes geographies, roadway types, speed range, weather, time of day, and state and local traffic laws and regulations. • Developing self-driving technology that can navigate city streets in a variety of conditions within broad geographic areas. Vehicles are designed with the capability to drive in inclement weather, such as light to moderate rain, and can operate in daytime and at night.
ARGO AI (FORD)	• The vehicles will be equipped with technology designed to detect and respond to static external environments, such as road structures and features (e.g., curbs, lane markings and barriers), roadside objects (e.g., trees and debris), dynamic objects (e.g., cars, trucks, motorcycles, and bicycles) as well as pedestrians, first responders and animals. Also, vehicles will operate day and night under a variety of light conditions as well as during precipitation capped at light rain.
CRUISE (GM)	• Vehicle's ODD will include the streets in the cities where the vehicle will operate, and operation at all times of day and night, and in light-to-moderate inclement weather (e.g., fog or rain). • Determine the appropriate environments and conditions using the System Safety engineering process. • Rigorously test and validate the self-driving vehicles so that they have the skills and experience to navigate the environment safely.
BMW iNEXT	• Within its geographical ODD, the SAE Level 3 BMW ADS can only be activated and operate on limited access highways with continuous structural separation from oncoming traffic and no direct crossing traffic or roundabouts. This road type is characterized by a small probability of pedestrians and bicyclists being present. • SAE Level 3 BMW ADS is designed to function at speeds between 0 and 85mph. The speed of the vehicle will be adapted according to time of day, light conditions, if the roadway coefficient of friction is too small (e.g., if there is snow or ice on the road) or the wind is too strong.
APPLE	• Not reported
UBER ATG	• Three-pronged process to address the ODD: o Identifying the ODD using data sources such as Uber's existing lines of business. o Characterizing the ODD which includes leveraging externally sourced data, driving the area manually, adding data tags, synthesizing the tagged data, creating representative simulation and track tests. • Constraining the ODD by using geo-fencing techniques to prevent self-driving system from operating outside of the intended ODD; needing Mission Specialists to take manual control of the vehicle when presented with a scenario or conditions not included in the relevant ODD; preventing self-driving operation if prevailing environmental conditions are not in the vehicle ODD.
LYFT	• Self-driving vehicles are only deployed with safety operators in well-defined ODDs where the system meets the performance thresholds, under appropriate environments and conditions, defined using the system safety engineering process. • Specific additions to the ODD are incorporated based on technology development needs and only after completion of thorough review and assessment, including a safety and software sign-off. The safety operators are trained on the new ODD before executing on public roads.

Table 14 Object Event Detection and Response (OEDR) (3/12) – The perception by the system of any circumstance that is relevant to the immediate driving task, as well as the appropriate driver or system response to such a circumstance.

Entity	Approach / Description
WAYMO (GOOGLE)	• LiDAR - three types of LiDAR: short-range, high-resolution mid-range, and powerful new generation long-range LiDAR • Vision System - Helps the system spot traffic lights, construction zones, school buses, and the flashing lights of emergency vehicles. Waymo's vision system is comprised of several sets of high-resolution cameras, designed to work well at long range, in daylight and low-light conditions. • Radar System - Waymo's radar system has a continuous 360-degree view, so it can track the speed of road users in front, behind and to both sides of the vehicle. • Supplemental Sensors - audio detection system that can hear police and emergency vehicle sirens up to hundreds of feet away, and GPS to supplement the vehicles' extensive understanding of their physical locations in the world.
ARGO AI (FORD)	• LiDAR - The LiDAR sensors can see more than 250 meters, which is almost three football fields in length. • Radar - The radar helps identify objects and the rate of speed of other vehicles. • Far-Field and Near Field Cameras - The cameras can recognize, classify, and track objects including pedestrians and bicyclists.
CRUISE (GM)	• LiDAR - High-precision laser sensors that detect fixed and moving objects. • Cameras - Detect and track pedestrians / cyclists, traffic lights, free space, and other features. • Radars - Three types of radars: short-range radars detect objects around the vehicle; long-range radars detect vehicles and measure velocity; articulating radars detect moving vehicles at long range over a wide field of view.
BMW iNEXT	• Camera: Sensor with highest extractable information content as it is capable of capturing visible cues comparable to human perception. Limited precision in range determination, high sensitivity to adverse conditions. • LIDAR: High-precision measurement of structured and unstructured elements. Medium sensitivity to environmental conditions. • Radar: High-precision detection and measurement of moving objects with appropriate reflectivity in radar operation range, high robustness against weather conditions. • Ultrasonic: Well-established near-field sensor capable of detecting closest distances to reflecting entities.
APPLE	• The combined use of sensors, including LiDAR, radar, and cameras provide a high-resolution 360-degree 3D coverage around the vehicle to determine where the vehicle is located in the world and to identify and track surrounding objects (other vehicles, pedestrians, and bicyclists). • The next action for the ADS is determined by using ADS's detailed map and accurate positioning technology, together with information from the sensing component and predicting where the vehicle and every surrounding object will be many seconds into the future.
UBER ATG	• LiDAR - Uber ATG's self-driving system utilizes a LIDAR unit with a range of over 100 meters (m). • Cameras - Uber ATG self-driving vehicle is equipped with cameras that provide high resolution, near-, medium-, and long-range imagery. • Radar - Uber ATG self-driving vehicle is equipped with radars that provide object detection, ranging, and relative velocity of objects. • GPS - The onboard GPS receives GPS satellite signals to provide useful vehicle position information in support of localization, vehicle routing, and map data collect missions.
LYFT	• LiDAR sensors capture a 3D representation of the world around the vehicle and highlight potential objects and events. • Cameras generate images that help accurately detect and classify objects. • Radars provide reliable distance and speed information for detected objects. • These instruments are carefully calibrated along with other supporting sensors to provide a consistent view of the world, guiding the vehicle's perception pipeline.

Entity	Approach / Description
	• Several categories of historical road information are precomputed in the form of HD maps to guide navigation. Publicly available information for sources, as well as sensor data collected on previous drives are used and structured into a series of "layers": base, geometric, semantic, prior, real-time layers.

Table 15 Fallback (Minimal Risk Condition) (4/12) – Transition to a minimal risk condition (safe state) in the event of a problem with the self-driving system that prevents continued safe operation

Entity	Approach / Description
WAYMO (GOOGLE)	Waymo's self-driving vehicles are equipped with a secondary computer that can take over in the event of a main computer failure, bringing the vehicle to a safe stop (i.e., a minimal risk condition).
ARGO AI (FORD)	Depending on the severity of the problem, the vehicle will transition to an appropriately safe state, ranging from a diagnostic report to stopping as soon as possible. Vehicles rely on a comprehensive, robust diagnostics strategy, including a main Virtual Driver System and backup system sharing information.
CRUISE (GM)	The vehicle has two main sets of computers, one primary and one backup. They operate independently and simultaneously for self-driving decision-making. Should a malfunction occur, the diagnostics system determines whether the appropriate response is a fail-operational state or a fail-safe state and transitions the vehicle to the corresponding safe state.
BMW iNEXT	The production version of the BMW iNEXT vehicle will transition control of the vehicle to the human driver when either the vehicle determines that the conditions detailed in ODD are no longer met or if there is a failure in the ADS system that prevents the SAE Level 3 BMW ADS from fully maintaining control of the driving task. In the event that the fallback-ready user (i.e., the human driver) is not receptive to the warning cascade of the takeover request, the SAE Level 3 BMW ADS will perform a risk mitigation maneuver. This simply means that the vehicle will take an action up to and including bringing the vehicle to a safe stop on the hard shoulder or in the traffic lane if reaching the shoulder is not feasible, for example during heavy traffic.
APPLE	In the event of an incident, testing is paused until data logged by the ADS is reviewed and an internal investigation is completed. Testing is resumed if it is determined that the ADS or safety driver acted appropriately during the incident. If the ADS or safety drivers was at fault, testing is resumed after all corrective actions are verified and implemented.
UBER ATG	Use of robust and thoroughly tested components, designing key redundancies (e.g., steering, braking) into the system, and implementing a subsystem that monitors the system for faults and takes action when they occur. Redundancies and fault detection software are tenets of fault tolerant system design.
LYFT	Self-driving system monitors safety-critical aspects 100 times every second. In the event of a detected failure, the system can automatically disengage and simultaneously inform the operators to resume full manual control of the vehicle. Furthermore, the motion of the AV is controlled within a safety envelope, or buffer, whereby the safety operators are able to maintain vehicle control, if needed.

Table 16 Validation Methods (5/12) – Verification of the self-driving system so that risks during operation are minimized.

Entity	Approach / Description
WAYMO (GOOGLE)	After testing the base vehicle, the self-driving system, and the software individually, the fully integrated self-driving vehicle is tested which includes closed-course collision avoidance testing, reliability and durability testing, and on-road testing with trained test drivers at the wheel.
ARGO AI (FORD)	Ford uses a proven three-step method for validation: simulation, closed-track testing, and real-world testing. Simulation techniques include Hardware-in-the-Loop (HIL) and Software-in-the-Loop (SIL) to create virtual sandboxes for component and sub-system testing.
CRUISE (GM)	Validation includes track testing, staged encounters, test cases and simulations to test self-driving vehicle itself against a variety of objective tests and performance requirements. Validations with on-road performance testing is also carried out, where millions of miles of test data are collected to show on a statistically significant basis that the vehicle is safe.
BMW iNEXT	For validation, the SAE Level 3 BMW ADS is additionally tested at various levels against a variety of pre-defined realistic scenarios and in real-world traffic. Several tools are used in this context including: Hardware/Software (HW/SW) open-loop reprocessing, HW/SW-in-the-loop simulation (e.g., driving strategy including minimum-risk condition); customer studies in driving simulator (e.g., driver-vehicle interaction); real-world test drive open-loop (e.g., sensor performance) and closed-loop (e.g., driving dynamics). Lastly, the closed-loop test drive in the target vehicle is also used for full-vehicle validation to ensure that the systems operate appropriately on the road.
APPLE	Validations test are designed to test the hardware and software in environments that mimic the operating environment and inputs that would be expected at each level of integration. Furthermore, rigorous test plans are designed to be executed in simulation, test benches, and testing at closed course proving grounds. After rigorous simulation testing, the entire system undergoes on-road testing at closed-course proving grounds. Safety critical changes undergo an extra phase of testing conducted by the most experienced drivers and operators.
UBER ATG	Uber employs a rigorous verification and validation process from an initial software change through real-world testing which include offline testing, simulation, test scenario development, track verification testing, on-road validation testing.
LYFT	Validation tests include software-in-the-loop environments for replay and system and component testing; hardware-in-the-loop environments for sub-system testing; parametric simulation with environment calibration and validation using real-world test data; structured testing of AV features and end-to-end behavioral competencies at test tracks, including private test facility in East Palo Alto, CA and other closed course locations; Public roads with trained safety operators.

Table 17 Human Machine Interface (6/12) – Refers to the design of interactions between the self-driving vehicle and people, both inside and outside of the vehicle.

Entity	Approach / Description
WAYMO (GOOGLE)	Waymo's user experience is guided by four main principles: give passengers the information they need for a seamless trip; help passengers anticipate what is next; proactively communicate the vehicle's response to events on the road; and help passengers engage safely with the vehicle. Multiple ways are available for the riders to interact with the vehicle, whether it is through the pressing of physical buttons, a mobile app, or by speaking with a Waymo rider support specialist.
ARGO AI (FORD)	The interface begins when hailing a ride or placing a delivery order through the mobile app. Once inside and briefed on both the trip ahead and safety features, including a reminder to buckle up, passengers will press a button in a touchscreen accessible from each row of seating that indicates they are ready to go. Most information will be delivered visually via text and graphics with occasional audible commands. Should someone decide an unplanned stop is necessary, a pull over request button will be available for each row. Pressing it will trigger a stop at the next secure waypoint within the vehicle's ODD and depending on the context may also prompt a call from a customer service representative to inquire about the matter. Once the vehicle arrives at its destination, passengers have an option to either dismiss the vehicle via their app or onboard touchscreen or asking it to "hold" for a few minutes while they retrieve children, luggage, and or groceries. A "secure hold" feature locks the doors until unloading is completed.

Entity	Approach / Description
CRUISE (GM)	Customers will begin their interaction with the self-driving vehicle before they get in the vehicle by using a mobile application to request a ride. Once inside the vehicle, the customers will use touchscreen tablets with an intuitive interface allowing riders to control the HVAC and radio, access general information about the vehicle, and receive real-time status information pertinent to the current ride. Before the ride begins, the tablets will provide helpful safety reminders, such as to close all doors and fasten seat belts. The vehicles will also have OnStar Automatic Crash Response. Built-in sensors can automatically alert an OnStar Advisor and predict the severity of injuries. An Advisor is immediately connected into the vehicle to see if passengers need help, even if they cannot ask for it.
BMW iNEXT	With Level 3 BMW ADS, the user's driving experience will be enhanced even further by providing them the opportunity to temporarily hand over the Dynamic Driving Task (DDT) to the ADS when operating within the SAE Level 3 BMW ADS's Operational Design Domain (ODD). The system includes a driver-monitoring system to observe whether the fallback-ready user is awake, is sitting in the driver's seat, and has the seat belt fastened. To detect if the driver has taken over the driving task after a take-over-request (TOR) the driver monitoring system also contains a hands-on-detection-sensor in the steering wheel, a steering-torque-sensor, and pedal-position-sensors. Other HMI design solutions include color coded illumination of the steering wheel during Level 3 activity, communication of a successful TO by the user via different channels, combination of auditory and visual elements to ensure smooth transitions between levels of automations, and optimization of the sensory component of the HMI for the specific scenarios the user is confronted with.
APPLE	To ensure that drivers and operators can quickly identify a system malfunction and take control of the vehicle, the following measures are in place: persistent visual display of the system's mode; a visual and audible signal indicates when the system needs to return control to the safety driver; multiple, redundant, and fault-tolerant mechanisms for taking control of the vehicle; the steering, braking, and acceleration commands issued by the ADS have set limits to ensure that its actions can be anticipated and interrupted by the safety driver.
UBER ATG	Self-driving vehicles are equipped with a touchscreen tablet that communicates important information to the Mission Specialists, including turn-by-turn directions for the planned route and whether the system is currently under manual or self-driving control. During current operations, the touchscreen does not require any input from the Pilot while driving; minimizes use of text, background information, and options for interaction; uses audio and user interface transitions and map motion to clarify information presented; employs a visual system focused on color, iconography, and visual layout to improve glanceability; optimizes color for time of day.
LYFT	The driver-facing visual HMI element displays the state of the AV system in a simple, robust, and easily interpreted manner to minimize distraction. The co-pilot's HMI is a more comprehensive visual interface that provides greater detail about the vehicle status, surroundings, intent, and system health. The co-pilot's HMI also provides a method of notetaking and system control, when necessary. Lyft's AVs are outfitted with two layers of audio HMI: one informs operators of any disengagement from autonomous control, allowing smooth transition to manual control of the vehicle; the secondary audio system provides a wide range of notifications to inform operators and riders about trip updates, AV system status, and customer support functions. The Lyft app is riders' first touch point with the self-driving vehicle, and it works hand-in-hand with on-board HMI components to share necessary safety information. Once inside the vehicle, all riders have access to ride-critical information, including their location along the route and status of critical safety systems. This display also provides riders with information intended to convey how the AV is able to safely interact with the world around it. All passengers in the vehicle have immediate access to remote assistance agents at any time during a ride.

Table 18 Cybersecurity (7/12) – Protecting the vehicles and the riders/operators from unauthorized access

Entity	Approach / Description
WAYMO (GOOGLE)	Waymo has developed security practices built on the foundation of Google's Security processes and are informed by publications like the NHTSA Cybersecurity Guidance and the Automotive Information Sharing and Analysis Center's (Auto-ISAC) Automotive Cybersecurity Best Practices. To help develop future security best practices, Waymo has also joined the Auto-ISAC, an industry-operated initiative created to enhance cybersecurity awareness and collaboration across the global automotive industry.
ARGO AI (FORD)	Current design features are rigorously tested against the library of threats and attacks. This library is constantly updated, cross referencing Common Vulnerability and Exposure (CVE) alerts from the National Institute of Standards and Technology (NIST) and other threat sources. Ford is a founding member of the Auto-ISAC and chairs some of the SAE Cybersecurity work groups, and efforts are aligned with the NHTSA Cybersecurity Best Practices for the Modern Vehicle.
CRUISE (GM)	Dedicated cybersecurity specialists analyze and addresses cybersecurity for all in-vehicle control systems, as well as any self-driving vehicle connected services (such as OnStar), mobile apps and in-vehicle apps created for the self-driving experience. Collaboration with industry include working with suppliers, joint ventures, various automotive and security consortia, government agencies, the security research community and the Auto-ISAC. In addition, security practices are regularly assessed against guidance from NHTSA, NIST, Auto-ISAC and other industry experts.
BMW iNEXT	BMW has implemented numerous processes to handle cybersecurity incidents, analyze threat intelligence and exchange it with external entities, and to develop and roll-out security updates to the vehicle. BMW is an active participant in the Auto-ISAC. For all on-board and off-board vehicle systems, including connected devices and the BMW back end, BMW has implemented a security architecture that utilizes the security-by-design approach and is based on the latest industry best practices. For all cyber-physical systems, basic protection levels have been implemented, which may include encryption and authentication. Furthermore, for the vehicle's most critical systems and data, additional safeguards have been implemented to achieve an even higher protection level for BMW customers and all road-users in general.
APPLE	Apple conducts threat assessments and takes steps to mitigate known and anticipated risks. This security approach is applied throughout the development of the ADS to ensure safe operation on the road, to prevent data theft and tampering, and to protect privacy and intellectual property. Data collection practices are guided by Apple's belief that privacy is a fundamental human right. Sensitive data are protected, and data collection are limited to only what is needed for the development of the ADS.
UBER ATG	Cybersecurity approach is informed by best practices described by NHTSA and relevant industry groups, including ISO, SAE International, and the Automotive Information Sharing and Analysis Center (Auto-ISAC). Uber ATG adopts and designs controls with the expectation that high-risk domains (e.g., cellular-adjacent devices) may be occupied or manipulable by malicious actors. Uber ATG has designed and is employing security-specific principles, controls, and technologies within the self-driving computer, vehicle platform, and network infrastructure.
LYFT	Methodical approach to security design, based on cybersecurity best practices followed by the IT industry, as well as guidance provided by NHTSA and Auto-ISAC. Adversarial risks are identified, and critical assets are prioritized with appropriate defenses. Based on this prioritization, the product requirements are developed around these assets, and then detailed engineering designs are developed that span the entire connected system to meet these product requirements. These designs are then implemented at the individual component level and tested through each layer and at various integration levels to ensure alignment with Lyft's cybersecurity standards.

Table 19 Crashworthiness (8/12) – Protecting occupants in the event of a crash

Entity	Approach / Description
WAYMO (GOOGLE)	Analysis of video and other sensor data to evaluate factors contributing to the crash and changes or updates to software applied in every vehicle based on the analysis. Damage to vehicles repaired and tested for safety before returning to the road.
ARGO AI (FORD)	Computer-aided modeling, engineering assessments, component testing, subsystem / sled testing and full vehicle system evaluations are included in the crashworthiness process. Restraints (seatbelts, airbags) and structural elements (bumpers, rails, and pillars) are optimized to reduce acceleration and loads occupants experience during a crash. On-going research with University of Michigan Transportation Research Institute and Virginia Tech Transportation to enhance passenger safety.
CRUISE (GM)	Safety standards incorporated following the specifications in FMVSS. Crashworthiness strategies include engineered load paths and vehicle floor reinforcements to protect occupant space, battery housing structure protecting the internal battery.
BMW iNEXT	Safety standards incorporated following the specifications in FMVSS, considering consumer tests (NCAP), and BMW Group's internal standards. BMW iNEXT concept vehicle will be equipped with rollover, inertial and pressure sensors to activate restraint systems and shut down the high electric system. BMW iNEXT vehicle will balance energy distribution and load paths during a crash.
APPLE	Modifications to occupant compartment are ensured to not interfere with airbags and seatbelts by placing them in secure mounting locations.
UBER ATG	UBER ATG selects Volvo XC90 sport-utility based on its top-safety ratings for incorporating self-driving technology. Volvo has certifications from FMVSS for these vehicles. Key crashworthiness features include seatbelts with pretensioners and load limiters, curtain airbags to protect occupants from front and sides.
LYFT	Minimal modifications to the base vehicle to ensure the safety systems put in place by the OEM are unaltered.

Table 20 Post-Crash ADS Behavior (9/12) – The vehicles return to a safe state after a crash to protect the riders.

Entity	Approach / Description
WAYMO (GOOGLE)	Notifications sent to Waymo operations center after a collision and the post-crash procedures initiated. Riders can communicate with support specialists through the in-vehicle audio system.
ARGO AI (FORD)	The vehicle enters minimal risk condition and depending on the severity of the crash the following actions are implemented: calling 911 through the embedded modem; power from the main battery is turned off (if required) and secondary power unlocks doors and turns on hazard lights; relevant crash data are logged automatically for future analysis; service representative communicates with occupants to ensure safety and facilitate communication with first responders; second self-driving vehicle is dispatched to complete the trip or technicians are sent to repair/tow the vehicle if necessary.
CRUISE (GM)	The vehicle enters a safe state. Built-in sensors alert OnStar advisor who then sets up communication with occupant and first responders. Depending on the severity of the crash, emergency help is dispatched by the OnStar advisor and the vehicle's crash response system unlocks doors and turns on hazard lights.
BMW iNEXT	After a crash if the BMW ADS cannot function safety, takeover request (TOR) is initiated to the human driver and if the driver fails to respond minimal risk condition processes are initiated. For severe crashes, mechanisms are incorporated into the vehicle to unlock the doors, disconnect the high voltage battery, activate the hazard lights, engage brakes to prevent secondary collision, and initiate call to BMW response center.
APPLE	Testing is paused in the event of an incident and the data logged by the ADS is reviewed and internally investigated to determine cause and appropriate response in terms of testing and validation of the faulty system component.
UBER ATG	Post-impact safety features function and perform the following actions: deploying front and side curtain airbags, activating seat-belt tensioners, and unlocking doors; safety mode with reduced vehicle functionality is activated; stopping the vehicle to prevent disruption to traffic operations; hazard lights illumination; disconnecting the high voltage battery and fuel supply to the engine.

Entity	Approach / Description
LYFT	ADS loses control of the base vehicle in the event of a crash and all modifications are marked for first responders to safely maneuver through. AV response teams are dispatched to assist the operators and any impacted third-party.

Table 21 Data Recording (10/12) – Data from self-driving vehicles feed powerful analytical tools that can be used to maximize the safety potential of self-driving vehicles.

Entity	Approach / Description
WAYMO (GOOGLE)	Robust system to collect and analyze data from road encounters. Crashes are reported consistent with state law. Any modifications to the self-driving system are applied to the entire fleet.
ARGO AI (FORD)	Continuous data recording during simulations and test runs provides useful information to refine approach and build better systems. Event Data Recorders (EDR) compliant with the regulatory standards are used for data recording during crash events. Autonomous vehicle data storage device will log information from onboard systems and the virtual driver system which will be used during scheduled maintenance.
CRUISE (GM)	EDR and second robust data logging system has self-diagnostics, store data securely even in the event of a crash. Data from sensors and vehicle actions are stored for event reconstruction. Other uses of the data include design and performance evaluation, improvement for future vehicles.
BMW iNEXT	EDRs are used for data recording regulated by NHTSA and governed by applicable data privacy laws and guidelines. Data stored on the EDR are encrypted and in the case of a crash, only data required by law and data to reconstruct the crash are stored.
APPLE	Any changes to the system including operational policies and training are data-driven which are collected from safety evaluations, disengagements, simulations, and testing on proving grounds.
UBER ATG	Environmental and systems data are recorded. Data are used for system performance analysis, quality assurance, machine learning and testing, simulated environment creation and validation, software development, human operator training and report, map building, and validation.
LYFT	Data logging system records ADS input and output parameters, AV sensor data and actuator responses. Post incident these data are analyzed and contributing factors are determined to prevent or minimize the recurrence of such event through updates to the ADS.

Table 22 Consumer Education and Training (11/12) – Proper education and training facilitate increased safety during the deployment of self-driving vehicles.

Entity	Approach / Description
WAYMO (GOOGLE)	Helped launch world's first public education campaign about fully self-driving vehicles. Trainings conducted with law enforcement and first responders.
ARGO AI (FORD)	Information about development milestones is planned to be disseminated to public through various communication channels such as blog, traditional media outreach and social media platforms. Appropriate materials are planned to be developed on how to request a ride, how to order and interact with delivery vehicles work, including safety.
CRUISE (GM)	Planned to publish material informing consumers about what to expect when using the ride-sharing service to obtain rides. Publication will consist of information regarding requesting rides, identifying the self-driving vehicle that is assigned for the requested ride, expectations during the ride, and at the end of the ride.
APPLE	Not reported
UBER ATG	Consumer education and interaction through blog posts, community events, town hall sessions, operation notices, and feedback collection.
LYFT	Communication with rider during a self-driving ride, in-car education, and offering riders multiple ways to provide feedback. Pilot program allows riders to experience self-driving technology in select markets and leave feedback.

Table 23 Federal, State, and Local Laws (12/12) – Entities are encouraged to document how they intend to account for all applicable Federal, State, and local laws in the design of their vehicles and ADSs.

Entity	Approach / Description
WAYMO (GOOGLE)	• Waymo complies with federal, state, and local laws by incorporating the legal requirements in their ODD. • Legal requirements, and any changes in those requirements, are identified and built into the system as safety requirements, including relevant speed limits, traffic signs, and signals. • New locations are scrutinized for unique road rules or driving customs by the Waymo team.
ARGO AI (FORD)	• Ford acknowledges their obligations to meet FMVSS. Ford vehicles will comply with all applicable requirements. • Ford is currently working with NHTSA, VTTI and other stakeholders to update FMVSS regulations in light of self-driving vehicles' unique features. • Ford has worked with the Michigan State Police to better understand edge cases unique to first responders and will incorporate their feedback into designing HMI for those encounters. • Ford will also continue its commitment to the environment with self-driving vehicles that meet or exceed all applicable fuel economy and emissions regulations.
CRUISE (GM)	• Cruise AV will comply with federal laws and meet all applicable FMVSS. Where FMVSS cannot be met because they are human-driver-based requirements, the vehicle will meet the safety purposes of those standards and Cruise will petition for exemption (permission to meet the safety purpose of a standard through alternative means). Cruise has filed such a petition for the Cruise AV. • The self-driving vehicle will also comply with federal laws and regulations relating to fuel economy, emissions, noise, hazardous materials, and labelling requirements. • Cruise is working with industry groups and NHTSA to advance the development of new FMVSS that will (a) remove unnecessary roadblocks to new safety technology, such as self-driving vehicles, and (b) advance the safety of self-driving vehicle technology. • Cruise AV is designed to be capable of complying with state and local laws applicable in its ODD. • Cruise AV will comply with non-traffic-related state and local laws, such as insurance requirements, reporting requirements related to field incidents and interventions, and others. • Cruise AV will communicate with and educate first responders on how their self-driving vehicles implement local law requirements (like where to find the registration and insurance) and what first responders can expect when encountering the self-driving vehicles.
BMW iNEXT	• Active engagement with stakeholders in order to share BMW's approach to ADS and provide input for potential new regulations that will govern the development and deployment of ADS-equipped vehicles into the market. • BMW is thoughtfully deploying its SAE Level 3 BMW ADS according to the best practices established by relevant industry and governmental organizations. • ADS vehicles will be equipped with Over the Air (OTA) updating capabilities to incorporate any regulatory framework changes.
APPLE	• Apple appreciates the importance of proactive and candid engagement with federal, state, and local government agencies that play a critical role in advancing the development and deployment of ADS. • Apple recognizes the value and need to be transparent with government officials about ADS testing on public roads, and vigilantly adheres to the relevant regulations and requirements. • Apple established constructive working relationships with federal, state, and local government agencies and stakeholder groups to facilitate information sharing on current and future technological, regulatory, and public policy matters.
UBER ATG	• Uber ATG recognize the USDOT's consideration of potential value of new regulations specifically focused on self-driving vehicles. This includes, but is not limited to, new FMVSS and/or changes to existing FMVSS that may be promulgated to address unique features of self-driving vehicle design and capability, or to allow for test features specific to self-driving vehicles. • When developing autonomy capabilities, the relevant traffic laws and norms for a given ODD are assessed to ensure that those rules are integrated into the self-driving system. Formal limits are enacted within the self-driving system software to reflect these rules.
LYFT	• To promote innovation and enable AV technology to reach its full potential, Lyft will continue to engage in active discussions with governmental stakeholders to advocate for the adoption of technology-neutral policy solutions, ensuring a level playing field for all participants, not just traditional

Entity	Approach / Description
	auto manufacturers. Lyft looks forward to the opportunity to work with other stakeholders as they further expand their program.

SAFETY APPROACH IN DEVELOPING AND DEPLOYING AVs BY THE INDUSTRY ENTITIES

Table 24 summarizes the design aspects and the safety approach adopted by the industry entities in developing and deploying AVs. It should be mentioned that the information provided here is obtained from the safety approach reports prepared by each of these entities. For instance, Waymo by Google safety approach is to test hardware initially while having a safety driver at the steering wheel. Subsequently, Waymo carries out tests at private test tracks, labs, and in simulation. This testing seeks to ensure that the vehicles continue to function safely after the addition of Waymo's self-driving system. Argo AI by Ford investigates various testing components including safety, reliability, and consumer experience. For safety, a two-person team consists of a safety driver and a co-pilot undergo rigorous training and certification prior involvement in testing. The company utilizes simulation techniques including Hardware-in-the-Loop (HIL) and Software-in-the-Loop (SIL) to create virtual sandboxes for component and sub-system testing. Real-world testing generates the miles logged and near misses encountered to either validate system safety or to refine requirements with fresh data for simulations. In parallel with technology development, Argo AI design and test customer experiences utilizing innovative approaches to better understand how users respond to automated driving systems.

Table 24 Design aspects and the safety approach adopted by the industry entities

Company	Tested Component	Testing level	Description of Actions
WAYMO (GOOGLE)	Hardware testing	Manual Mode	After the integration of the self-driving components into the base vehicle, Waymo carries out tests at private test tracks, labs, and in simulation. This testing seeks to ensure that the vehicles continue to function safely after the addition of Waymo's self-driving system.
		Self-driving mode with a test driver at the steering wheel	
		Fully self-driving mode without a safety driver	
	Software testing	Simulation Testing	Test any changes or updates to software before they are deployed. Turns real-world challenging situations into virtual scenarios for self-driving software to practice in simulation.
		Closed-Course Testing	Develop and test behavioral scenarios to ensure the self-driving vehicles can safely handle the challenges of real-world environments. The testing is carried out in private test track to ensure the suitability of any new software updates.
		Real-World Driving	The new software is introduced to vehicles on public roads in phases. At first the software needs to perform safely on predetermined routes before being pushed into the entire fleet.
	Testing the fully integrated self-driving vehicle	Testing Crash Avoidance Capabilities	Rear-end, intersection, road departure, lane change crashes are prioritized and tested across a variety of scenarios.
		Hardware reliability and durability testing	Unique stress tests are conducted to analyze the failures and make design improvements to increase the reliability of the components. Stress tests include ultraviolet radiation, powerful water jets, freezing water, corroding in salty mists, shake and shock with powerful vibrations, heat and freeze for weeks in temperature and humidity chambers.
ARGO AI (FORD)	Safety	Safety operator training	A two–person team – a safety driver and a "co-pilot" undergo rigorous training and certification before being put in all the test vehicles.
	Reliability	Virtual driver system	The system capable of being an SAE Level 4 AV consists of sensors to see around the vehicle, algorithms to predict next move, highly detailed 3D maps, and precise internal measurement systems
		Diagnostics and health monitoring	Diagnostics integrated across multiple systems within the vehicle to determine vehicle health and perform fallback maneuvers when needed. Vehicles are monitored for readiness.
		Simulation	Simulation techniques include Hardware-in-the-Loop (HIL) and Software-in-the-Loop (SIL) to create virtual sandboxes for component and sub-system testing. There's on-going collaboration with Virginia Tech Transportation Institute and industry to collect novel data and create baseline datasets for simulation.
		Closed-track testing	Vehicles are subjected to edge cases and difficult situations in a simulated urban course. Deliberated fault-injection into fail-functional components, such as braking and sensors, tests the system's ability to transition to a Minimal Risk Condition during malfunctions with safety operators able to retake control at any time. Electromagnetic compatibility, durability and environmental testing are carried out to validate the robustness of the OEDR.
		Real-world testing	Real-world testing generates the miles logged and near misses encountered to either validate system safety or to refine requirements with fresh data for simulations.

Company	Tested Component	Testing level	Description of Actions
	Valuable experiences	Consumer oriented development	Designing and testing customer experiences in parallel with technology development. Innovative approaches are employed to engage consumers to better understand how they will respond to self-driving vehicles.
		Pilot programs	Conducting pilot programs that simulate the self-driving delivery experience by working with partner companies, such as Domino's Pizza and Postmates.
CRUISE (GM)	Engineering tools	Deductive analysis	Fault tree analysis (FTA), which connects potential hazards to their direct causes.
		Inductive analysis	Design and process failure mode and effects analysis (DFMEA/PFMEA), which is a step-by-step approach to identifying all possible hazards in a design.
		Exploratory analysis	Hazard and operability study (HAZOP), which identifies potential risks by analyzing the functions of a complex system.
		Implementation into the product development process	Using process hazard analysis at the concept stage to assess potential hazards, software HAZOP, system FTA and DFMEA during design, system functional interface analysis (SFIA) and DFMEA during requirements definition, and DFMEA during implementation phases.
		Requirements Traceability Analysis	Manages the relationships between engineered systems and the safety goals and attendant requirements.
	Operational Safety	Autonomous vehicle trainer (AVT)	Vehicles are monitored by trained AVT. During on-road testing, the AVT can take over control of the self-driving system when necessary or appropriate to be safe. Vehicle's data logger records the driver takeover events and the data from the logger is analyzed to assess the vehicle's self-driving performance and to decide whether to update the software.
		Differences in testing between cities	Testing in San Francisco predict an average of 32 times as many possible interactions as those in Phoenix. Thus, San Francisco challenges self-driving system more because, as the number of objects increase, there are exponentially more possible interactions with objects that the self-driving system must consider.
		Tests and simulation	Track testing, staged encounters, test cases, and simulations to test against variety of objective tests and performance requirements. On-road performance testing ensure statistical significance of vehicle safety.
		Validation processes	Vehicle-, system-, subsystem- and component-level performance tests; Requirements-based validation of system, subsystem and components; Fault injection testing of safety-critical control input, outputs, computation and communication; Validation of fail-over (transitioning to a secondary control path when the primary path malfunctions) and safe state transitions within the fault tolerant time interval; Intrusive testing, such as electromagnetic interference and electromagnetic compatibility testing, as well as other environmental element exposure tests (includes temperature, humidity, RF, light energy); Durability tests; Regression and simulation-based software validation.
APPLE	Overall System	Sense	The combined use of sensors, including LiDAR, radar, and cameras provide a high-resolution 360-degree 3D coverage around the vehicle to determine where the vehicle is located in the world and to identify and track surrounding objects (other vehicles, pedestrians, and bicyclists)
		Plan	The next action for the ADS is determined by using ADS's detailed map and accurate positioning technology, together with information from the sensing component and predicting where the vehicle and every surrounding object will be many seconds into the future.
		Act	The planning component's location and trajectory information is converted into commands for the vehicle's steering, braking, and propulsion systems. Furthermore, supporting hardware and software systems monitor the state of

Company	Tested Component	Testing level	Description of Actions
			safety critical systems and is capable of immediately transferring control of the test vehicles to the safety driver when needed.
	Crash Safety	Test vehicle	Test vehicles are based on a vehicle that is certified to the FMVSS and has top crashworthiness ratings in consumer crash tests.
		Equipment validation	External equipment undergo validation using simulation and physical testing before being mounted securely to minimize risk to surrounding road users.
		Internal modifications	Any modification inside the vehicle is analyzed to ensure no interference with airbags and seatbelts, and secure mounting locations that protect against injuries in the event of a crash.
	System Safety Analysis	Initial testing	If a potential hazard is identified during the development process, the design can be easily changed to prevent or reduce the identified hazards.
		Hazard analysis and mitigation	Malfunctions tested can include unintended vehicle motion, HMI hazards, and environmental hazards. Design changes to address the cause of any malfunction are identified and evaluated for effectiveness before they are incorporated into the design. Any malfunctions and scenarios that require the safety driver to take control of the vehicle to address a hazard are further studied to confirm that the safety driver could regain manual control of the vehicle safely. This includes simulations and vehicle testing with induced faults at proving grounds.
	System Verification	Verification tests	These tests are designed to test the hardware and software in environments that mimic the operating environment and inputs that would be expected at each level of integration. Furthermore, rigorous test plans are designed to be executed in simulation, test benches, and testing at closed course proving grounds.
		Simulation testing	All proposed changes to the ADS software are first subjected to rigorous and comprehensive simulation testing that evaluates the software against predetermined criteria.
		On-road testing	After rigorous simulation testing, the entire system undergoes on-road testing at closed-course proving grounds.
		Public road testing	Public road testing may be carried out only after passing the array of extensive simulations and closed course proving ground tests.
		Extra-tests	Safety critical changes undergo an extra phase of testing conducted by the most experienced drivers and operators.
	Operational Safety	Daily checks	Manual vehicle inspections and automatic diagnostic tests are carried out each time before a test run. Safety drivers and operators are consulted upon operational constraints, software updates, and any new information about test routes.
		Safety Drivers and Operators	Safety driver and an operator is required to be in the front seats for the current automated operation.
		Human Machine Interface	The following HMI measures are incorporated to ensure drivers and operators can quickly identify a system malfunction: persistent visual display; visual and audible signals to invite human intervention; multiple, redundant, and fault-tolerant mechanisms; limits set to steering, braking, and acceleration commands to allow safety driver to take control before and action is completed if required.
		Incident Response	In the event of an incident, testing is paused until data logged by the ADS is reviewed and an internal investigation is completed. Testing is resumed if it is determined that the ADS or safety driver acted appropriately during the incident. If the ADS or safety drivers was at fault, testing is resumed after all corrective actions are verified and implemented.
	Ongoing engagement	Federal, state, and local government	Proactive and candid engagement with federal, state, and local government. Transparency with government officials about ADS testing on public roads and adherence to relevant regulations and requirements is strictly maintained.

Company	Tested Component	Testing level	Description of Actions
UBER ATG	Mission Specialists	Current operation	At present, UBER ATG's self-driving vehicles are operated with two trained safety operators in the vehicle when on public roads. The Pilot, or operator behind the steering wheel, is solely focused on helping preserve safe operation of the vehicle, while the Co-Pilot, the second operator in the right front seat, is tasked with monitoring, communicating with the Pilot, and annotating the behavior of the self-driving system via a laptop.
		Role of Mission Specialists	UBER ATG's self-driving testing is carried out with Mission Specialists. Mission Specialists undergo training that prepares them to respond to scenarios such as those involving emergency vehicles, manually directed traffic, and routine traffic stops. They also undergo incident response training that prepares them to respond following an incident, including engagement with emergency personnel.
		Looking forward	As the performance of the self-driving system increases, the frequency of the need for intervention from a Mission Specialist would likely decrease — a dynamic that may raise its own challenges. Going forward, UBER ATG will continue studying human factors, effective assistive measures, and overall support structures for safe, self-driving vehicle operations.
	Base vehicle	Initial testing of base vehicles	Uber ATG's current testing and development efforts utilize vehicles that Uber ATG purchases from an Original Equipment Manufacturer (such as Volvo) and then subsequently modifies. Prior to Uber ATG's receipt of these vehicles, the manufacturer has certified its base vehicles as meeting all applicable FMVSS. Additionally, the effect of modifications by Uber ATG is assessed to ensure continued compliance with the Motor Vehicle Safety Act.
	Quality Processes	Offline testing	A sample of offline release tests include static analysis, unit tests, map compatibility test, onboard integration test, virtual simulation regression set test, reaction time metrics test.
		Hardware in the loop testing	Hardware in the loop testing ensures performance of software when running on representative hardware before being integrated into the vehicle's hardware.
		Simulation	Simulation tests have different permutations and combinations of traffic patterns, speeds, and trajectories for all the actors and objects in a scenario including the self-driving vehicle.
		Test scenario development	A scenario includes the physical environment as well as actors or objects and their static or dynamic paths. Each scenario is defined by a number of criteria for success, including considerations such as speeds, distances, and descriptions of safe behavior. Scenario documentation provides the basis for virtual scenario builds that can be run in simulation and on the test track. Scenario success criteria are aligned with applicable traffic laws.
		Track verification testing	Software releases that pass offline testing advance to Track Verification Testing (TVT).
		Hardware Design Quality	Hardware modules for the self-driving system undergo testing to confirm they are functioning properly, and to identify performance limits. Certain subsystems are tested in order to confirm effective interactions between components. This stage of testing also leverages HIL and simulation testing across hardware and software interfaces in a controlled environment. Fault injection testing is also performed at this level. Self-driving hardware and software components are integrated into the vehicle and tested to confirm performance of machine interfaces, electrical interfaces, and control path interfaces.
		Maintenance and repair	Uber ATG-managed self-driving vehicle fleets undergo extensive maintenance and monitoring routines to help ensure they continue to perform as expected. Prior to performing a day's mission, Mission Specialists subject the self-driving system to health checks and inspections to ensure it is ready for operations.

Company	Tested Component	Testing level	Description of Actions
	Ongoing engagement	Federal, state, and local government	Uber ATG is one of nine companies and eight States that have signed on as the first participants in a new initiative led by the U.S. DOT to improve the safety and testing transparency of automated driving systems called the Automated Vehicle Transparency and Engagement for Safe Testing (AV TEST) Initiative
LYFT	Pilot program	Self-driving ride with an operator	Self-driving pilot program allows Lyft riders to engage directly with self-driving technology today, through the same Lyft app. Lyft riders in select markets are able to request a self-driving ride just as they would a standard Lyft ride, and offer feedback directly through their Lyft app. All pilot program rides include a safety operator in the driver's seat who is focused on safety at all times.
	Operational safety	Safety approach	At this stage of development, Lyft's safety approach includes the presence of human safety operators who undergo rigorous operator vetting and selection process.
		Software	Software-in-the-loop environments for replay and system and component testing
		Hardware	Hardware-in-the-loop environments for sub-system testing
		Simulation	Parametric simulation with environment calibration and validation using real-world test data.
		Test tracks	Structured testing of AV features and end-to-end behavioral competencies at test tracks, including private test facility in East Palo Alto, CA and other closed course locations.
		Public road testing	Public roads with trained safety operators
	Operational checklists	Pre-operation inspection	The AV's interior and exterior are carefully inspected
		Malfunctions	Potential mission-critical issues, such as hardware or software malfunctions, are immediately mitigated and escalated with the assistance of the fleet technicians.
		Software checklist	Operators perform a software checklist for review before an AV can be operated again on public roads.
		Periodic maintenance	Lyft's fleet technicians perform weekly preventative maintenance and periodic inspections of hardware, sensors, and equipment to maintain fleet integrity.

Chapter 8 RECOMMENDATIONS

The final task of this research is aimed at providing WYDOT insights on the magnitude of the impacts of Automated Vehicles (AVs) on highway infrastructure. The recommendations in this report include: the development of Wyoming AV regulations, legislation, as well as guidance for testing and platooning procedures, the potential impacts of AVs on the physical and multimodal infrastructure, changes in traffic control devices and warrants for traffic signals.

Legislation and Policy

From the synthesis of the literature and statewide legislations and regulations pertaining to AVs, one common conclusion can be drawn and that is to provide regulations to encourage and allow autonomous vehicle testing and deployment. It was also found that rather than amending all chapters of motor vehicle or traffic law to include the use of AVs, the states considered establishing regulatory or policy actions as a separate chapter in existing legislations. Some states such as California, New Hampshire established separate guidelines for AV testing and deployment that included regulations such as testing permit requirements, licensing, registration, certification requirements, minimum insurance, safety reporting, etc. The synthesis also indicated that it is essential to develop guidance and regulations for truck platooning operations.

Testing vs. Full Deployment

- Guidance on application procedures for testing: notification to local jurisdictions; application fee; emergency response guide.
- Determine whether remote operators are required while testing and the licensing requirements.
- Increasing the insurance requirements for testing vs. full deployment.

- Safety plan from the testing entities for testing in challenging ODDs: adverse weather/road closures/work zones.
- Summary report of an entity’s approach for the safe testing of their autonomous system and how the entity intends to assure public safety.
- Define crash liability while testing vs. full deployment: manufacture's liability vs. owner’s liability.
- Monitor national AV testing and deployment guidelines based on evolving direction from the following sources: USDOT, NHTSA, FHWA, AAMVA, U.S. congressional actions.
- Remain technology neutral through testing and deployment to:
    - Avoid limiting development options.
    - Allow industry and markets to determine effective transportation technology solutions.
- Monitor national trends for training requirements in areas such as driver’s education, law-enforcement training, and first-responder training; and participate in applicable training.
- Require testing agencies to provide operational design domains that address issues such as local ordinances, bike lanes, pedestrian crossings, and school zones.

Truck Platooning Regulations

- Recommendation for the establishment of a working group to regulate truck platooning testing, testing permit.
- Establish platoon plans and policy regulations.
    - Locations (highways, bridges), restrictions, etc.

Infrastructure

As AV technologies become more mature, the need to study the infrastructure needs and requirements for AVs to include both physical and digital systems become more important.

Physical Infrastructure

- Access the adequacy of current infrastructure (pavements, bridges, and culverts).
- Short-term strategies:
  - Prioritize the roadways that are initially going to be open for AV testing.
  - Identify deficiencies within the roadways and flag them inadequate for AV operations.
  - Maintenance and minor improvement
- Long-term strategies:
  - Statewide assessment of existing structures.
  - Categorization into adequate/inadequate structures.
  - Increase resources for structural enhancement.
  - Revise and implement new design standards.
- Asset management using emerging technologies.

Pavement Markings

According to the NCUTCD CAV Task Force, the following areas were considered to be updated to accommodate AVs:

- Painted Lane- Boundaries with Good Contrast.
- Highly reflective pavement markings.
- Provide edge lines when curbs are presented.
- Non-dedicated exit lanes.
- Emergency areas/shoulders.
- Botts dots to assist machine vision.

- Short Dashed Lane Markings Indicating Exit Only Lanes.
- HOV/Express Lanes.
- Hatched areas for special marking.
- Increasing contrast of other pavement marking items: carpool lane, bike lane, large free space areas, lane endings and lane splits on highways, and speed bump notifications.

Other detailed recommendations mainly related to longitudinal whiter pavement marking were suggested as the new MUTCD updates. The MUTCD updates included:

- Increasing the normal line width from 4 to 6 inches for interstate and freeways and other roads with posted speed of 55 mph and ADT of 6,000 VPD or greater. Otherwise, 4 to 6 inches wide line could be used.
- Width of wide lines shall be 8 inches or more when used with 4-inch normal lines and 10 inches or more when used with 6-inch normal lines.
- 15-foot line segments and 25-foot gaps for broken lines should be adopted on interstates and freeways.
- Dotted lines shall be installed on exit ramps with tapered deceleration lanes.
- A normal width dotted white line extension may be installed for passing, climbing or truck lanes.

Traffic Signs

NCUTCD General Recommendations:

- Standardize all traffic signs throughout the entire country.
- Use mainly pictograms, limit use of text. In situations where text is necessary: The content of the text shall be standardized.
- Do not allow unique state specific traffic signs.
- All road signage should have good retroreflective background.

NCUTCD Recommendations for Electronic Signs:

- Retroreflective or illuminated white color should be provided for all electronic signs with black color text.
- Rectangular shaped signs should be used with standard length and width.
- Entire sign should be illuminated with a flicker/refresh rate above 200 Hz to be easier for the camera to detect.
- The location of the sign should not be above 17 feet in height from ground to the bottom of the sign.

NCUTCD Recommendations for Speed Limit Signs:

- Speed limit signs have to be associated with its specific route or lane.

NCUTCD Recommendations for School Signs

- School speed limit signs should be standard.
- Includes a yellow "SCHOOL" sign above a rectangular speed limit sign with standard dimensions.
- For conditional school signs, standard text shall be provided. If the school sign is electronic, a refresh/flicker rate above 200 Hz should be used.
- Signs should be placed on a height that does not exceed the 17 feet from ground to the bottom of the sign.
- "END SCHOOL ZONE" sign should be placed at the end of the school zone.

NCUTCD Recommendations for Future Signs

- 2D Infrared-readable barcode is a potential solution for future sign recognition.
- An imbedded barcode that identifies each specific sign could be placed on the signs using an optically transparent material.

Traffic Signals

- V2I communication could be used to send signal phasing to CAVs.
- Intelligent Intersection Control System (IICS), in which dynamic SPaT can be assigned based to CAV arrival rates based on V2I and I2V communication will enhance the operation and safety of road users.
- NCUTCD recommendations: uniformity in traffic signals placement, illumination, shape, refresh rates, and intensity could be helpful.
- Vertical traffic signal instead of horizontal ones with refresh rate greater than 200 Hz.
- Traffic lights should have a strip shape, where blocks, L-shaped, T-shaped are not allowed.
- A retroreflective sign can be placed for guidance, where appropriate.
- Traffic lights at the same location for different vehicles of other road users should not be close to each other to avoid confusion.
- Refresh rate and signal shape should follow the recommendations provided by the NCUTCD CAV task force.

Impact of CAT on Workforce and Engineering Curriculum

This section explored how undergraduate, graduate students, and professionals can be adequately prepared for future career related to CAV technologies, focusing on essential skillsets. The impact of autonomous technologies on the driving workforce was estimated to have affected approximately 50-57 percent of driving occupations as of 2019. The projection for automation levels 4 and 5 suggests near-complete implementation by 2050, causing significant annual displacement, peaking at 200,000 workers per year in the early 2040s. The adoption of Connected and Autonomous Vehicles (CAV) in the workforce, encompassing trucking and light vehicle scenarios, will shape the scale and timeline of this transformative shift. Although jobs displaced by CAV deployment are expected to be replaced after 2051, questions arise about workforce adaptation and retraining during the transitional period.

Efforts are in progress to integrate CAV technologies into engineering curricula, with dedicated courses recognizing the need for specialized education. The recommendation is to include additional CAV-oriented transportation and simulation courses for graduate and undergraduate engineering students, emphasizing the importance of integrating basic transportation engineering with CAV technologies. A proposed proactive strategy suggests introducing a Massive Open Online Course (MOOC) platform for universities. This platform would enable independent learning, allowing students to choose courses tailored to provide necessary knowledge and skills for industrial occupations. The aim is to keep the workforce agile and well-prepared for the evolving landscape of autonomous and connected technologies in the future.

Transportation Planning

It is essential to incorporate Autonomous Vehicles (AVs) into transportation planning studies to address their potential impacts on travel and land use. The transportation planning implications of AVs were thoroughly examined and synthesized by researchers. AVs are anticipated to alleviate many driving inconveniences, such as the challenge of finding parking, as these tasks can be handled by the vehicles themselves. These conveniences are likely to make AV-related modes more attractive than existing alternatives, influencing trip generation and distribution models, leading to an increase in vehicle trips.

The prospect of increased convenience and the potential for more productive use of time in autonomous vehicles may enhance individuals' tolerance for higher in-vehicle travel times. This, in turn, could impact the calculation of the value of time (VOT) used for the utility functions of the mode choice as a main transportation planning phase. Due to AVs' low reaction times and heightened awareness of their surroundings, they are expected to utilize road space more efficiently than human drivers. This efficiency has the potential to increase road capacities, directly influencing trip assignment models.

Public Acceptance

A survey questionnaire was formulated to gather the perceptions of Wyoming residents regarding Connected and Autonomous Vehicles (CAV) and Automated Driving Systems (ADS). The feedback from 1,062 participants underscored the perceived advantages of Connected and Autonomous Vehicle (CAV) technologies. Using a Structural Equation Model (SEM), the results revealed that public acceptance of CAVs was primarily influenced by their acceptance of CAVs in Emergency Medical Services (EMS) and concerns about the privacy of personal data. This acceptance was indirectly influenced by public confidence in CAV technology and considerations related to operational liability and performance.

To tackle these challenges, it is advisable to initiate public education campaigns with a primary focus on promoting the safety and security of personal information. Additionally, a critical priority is the development of robust security architectures and intrusion detection systems capable of detecting and preventing cyberattacks, ensuring the successful deployment of CAVs. Furthermore, concerns among the public about liability issues for CAVs, particularly in Level 5 Autonomous Vehicle (AV) crashes, indicate a need to shift liability away from the driver.

OEMs Safety Approach

Autonomous vehicle manufacturers are advised to incorporate safety considerations into the design of their systems. Although there is no universally accepted standard for evaluating manufacturers' adherence to safety elements, it is anticipated that manufacturers document their protocols for evaluating, testing, and validating various system elements. The National Highway Traffic Safety Administration (NHTSA) anticipates the industry's ingenuity and innovation in devising optimal methods for mitigating safety risks associated with their respective approaches. Consequently, each entity involved in the manufacturing, testing, and deployment of autonomous vehicles is expected to address these safety elements in a distinctive approach.

In conclusion, the integration of cooperative automated transportation into Wyoming's highway infrastructure is anticipated to be extensive, encompassing improvements in efficiency, safety, economic dynamics, and environmental implications. The seamless integration of CAV technologies into the state's transportation framework necessitates a strategic approach, involving careful planning, the implementation of essential infrastructure upgrades, and the formulation of expert policies that account for emerging automated driving systems. Moreover, continuous caution through ongoing monitoring is imperative to gauge the system's performance and ensure its alignment with emerging trends. Adaptability and responsiveness to evolving CAV technologies will be paramount, allowing Wyoming to not only harness the full spectrum of benefits presented by cooperative automated transportation, but also proactively address and mitigate potential challenges that may arise in this transformative process.

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APPENDIX A

STATE REGULATIONS

State	Year	Content	URLs
National	2020	NCSL database of Autonomous Vehicles/Self-Driving Vehicles Enacted Legislation	NCSL.org
Alabama	2018	Definition and regulation of truck platoon	SB125
Alabama	2019	Definitions, regulation of commercial AV	SB47
Arizona	2018	Definitions, regulation of AV	EO2018-04
Arkansas	2017	Definition and regulation of truck platoon	HB1754
Arkansas	2019	Definitions, regulation of AV	HB1561
California	2015	Authorizing testing of vehicle platooning	SB719
California	2017	Definitions, regulation of AV	SB145
California	2019	Extension of vehicle platooning testing	AB1671
California	2020	Definitions, testing/deployment regulations of AV	Adopted Regulation Text
Colorado	2017	Definitions, regulation of AV	SB17-213
Delaware	2017	Establishment of advisory council	EO14
District of Columbia	2012	Definitions, regulation of AV	B19-0931
District of Columbia	2020	Autonomous Vehicles Testing Program Amendment Act of 2020	B23-0232
Florida	2016	Defines autonomous technology and driver-assistive truck platooning technology	HB7061
Florida	2019	Regulation of AVs	HB311
Georgia	2017	Regulation of platoon	HB472
Georgia	2017	Definitions, regulation of AV	SB219
Hawaii	2020	Definitions, regulation of AV	HB2591
Idaho	2018	Creating CAV testing and deployment committee	EO2018-01
Illinois	2018	Definitions, testing regulations of AV only	EO13-18
Indiana	2018	Regulation of platoon	HB1290
Iowa	2019	Definitions, regulation of AV	SF302
Kentucky	2018	Definitions, regulation of truck platoon	SB116
Louisiana	2018	Definitions, regulation of platoon	HB308
Louisiana	2019	Definitions, regulation of AV	HB455
Maine	2018	Establishes Advisory Committee	EO2018-001
Maine	2018	Establishes Commission of AV, allows testing, demonstration, and deployment	HP1204
Maryland	2017	HAV Permit Process	MDOT
Massachusetts	2019	Testing regulations and forms	MassDOT
Michigan	2016	Definitions, regulation of AV	SB995
Minnesota	2019	Definitions, regulation of platoon	HB6
Mississippi	2018	Definitions, regulation of platoon	HB1343
Nebraska	2018	Definitions, regulation of AV	LB989
Nevada	2017	Definitions, regulation of AV; Definitions, regulation of truck platoon	AB69
New Hampshire	2019	Definitions, regulation of AV	SB216
New Jersey	2019	Establishment of AV task force	AJR164
North Carolina	2017	Regulation of truck platoon	HB716

North Carolina	2017	Definitions, regulation of AV	HB469
North Dakota	2019	Regulation of truck platoon	HB1199
North Dakota	2019	Definitions, regulation of AV	HB1418
New York	2020	Testing regulations and forms	DMV
Ohio	2018	Definitions, regulation of AV	EO2018-04K
Oklahoma	2019	Definitions, regulation of platoon	SB189
Oklahoma	2019	Definitions, preemption authority provision	SB365
Oregon	2018	Establishment of AV task force	HB4063
Oregon	2020	Voluntary Notification of Automated Vehicle Testing	Form
Pennsylvania	2018	Definitions, testing regulations of AV	Guidance
South Carolina	2017	Regulation of truck platoon	HB3289
Tennessee	2017	Regulation of platoon	SB676
Tennessee	2017	Definitions, regulation of AV	SB151
Texas	2017	Regulation of platoon	HB1791
Texas	2017	Definitions, regulation of AV	SB2205
Utah	2018	Regulation of platoon	SB56
Utah	2019	Definitions, regulation of AV	HB101
Vermont	2019	Definitions, regulation of AV testing	SB149
Washington	2020	Self-certification for testing in Washington state	State DOL
Wisconsin	2018	Definitions, regulation of platoon	SB695

APPENDIX B

GLOSSARY

Autonomous commercial motor vehicle (Louisiana)	Motor vehicle used in commerce and equipped with an automated driving system, including those designed to function without a driver.
Commercial motor vehicle (Louisiana)	Motor vehicle or combination of motor vehicles used in commerce to transport passengers or property if the motor vehicle has a gross combination weight rating of twenty-six thousand one or more pounds inclusive of a towed unit with a gross vehicle weight rating of more than ten thousand pounds.
Dispatching entity	An entity that dispatches an ADS equipped vehicle in driverless operation.
Following too closely	The driver of a motor vehicle shall not follow another vehicle more closely than is reasonable and prudent, having due regard for the speed of such vehicles and the traffic upon and the conditions of the highway.
Full Deployment	The operation of an autonomous vehicle on public roads by members of the public who are not employees, contractors or designees or a manufacturer or other testing entity. Deployment also includes when a manufacturer sells, leases, or otherwise makes autonomous vehicles available for use outside of a testing program and the operation of AVs outside of a testing program.
Highly Automated Vehicle (Pennsylvania)	A motor vehicle with equipped with an ADS that can operate in high or full automation and where the ADS performs the dynamic driving task with no requirement that a driver, or a safety driver respond to any request to intervene or take control of the vehicle. This definition encompasses automated vehicles considered to be Level 3, 4 or 5 under SAE J3016.
Operate (SAE J3016)	Collectively, the activities performed by a (human) driver (with or without support from one or more level 1 or 2 driving automation features) or by an ADS (level 3-5) to perform the entire DDT for a given vehicle during a trip.
Operation (Pennsylvania)	The driving of a HAV on a trafficway for the purpose of testing an ADS.
Operational Design Domain (ODD) (SAE J3016)	The specific operating domain(s) in which an automated function or system is designed to properly operate, including but not limited to geographical conditions, roadway types, speed ranges, environmental conditions, and other domain constraints.
Platoon (Alabama)	A group of individual commercial trucks traveling in a unified manner at electronically coordinated speeds at following distances that are closer than would be reasonable and prudent without the electronic coordination.
Platoon (Pennsylvania)	Motor vehicles, buses, military vehicles, or motor carrier vehicles operated by a human traveling in a unified manner at electronically coordinated speeds at following distances that are closer than would be reasonable and prudent without such coordination.

Safety and Risk Mitigation Plan (Pennsylvania)	Operator focused plan and aims to ensure that the Tester has an adequate program to ensure driver training that encompasses both traditional driver performance expectations and proper driver-HAV test vehicle interaction.
Test operator (District of Columbia)	An employee, contractor, or other designee of the autonomous vehicle testing entity who engages an autonomous driving system and performs, in real time, part or all of the dynamic driving task.

APPENDIX C

User perception of Autonomous and Self-Driving Vehicles Questionnaire

Impacts of Cooperative Automated Transportation on Wyoming Highway Infrastructure

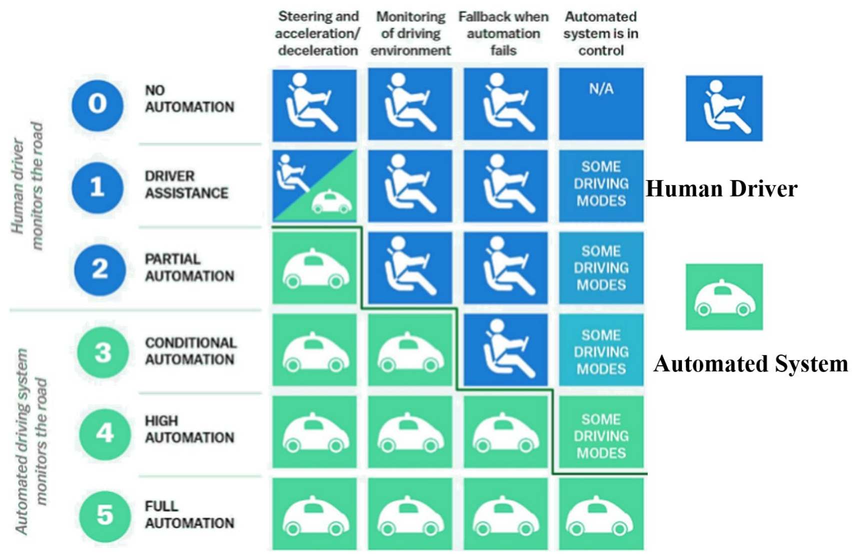
University of Wyoming (UW) and Wyoming Department of Transportation (WYDOT) Survey

SPONSOR: Wyoming Department of Transportation (WYDOT)

INVESTIGATOR: Mohamed Ahmed, Ph.D., P.E. - University of Wyoming, Department of Civil and Architectural Engineering

The era of autonomous driving is imminent. It is necessary to make sure that users are aware of the technology and its implications. This survey is designed to better understand the needs and perception of the users.
The survey is anonymous; no personally identifiable information will be collected from you. It would take approximately 10-15 min. to complete the survey. On successful completion, responders will be entered into a draw to win a $25 Amazon gift card.
Please note that the implementation and deployment of automated vehicles is not intended to remove or replace the ability to drive or use non-automated vehicles. Instead, the use of autonomous vehicles is being considered as an additional option when it comes to methods of transportation.

Automated technologies such as adaptive cruise control, automatic emergency braking, lane keeping assist, or steering assist have been in use in modern vehicles for quite some time now. Fully autonomous vehicles, or driverless vehicles, refer to those vehicles, which do not need any human intervention for the operation of the vehicle. There are six levels of driving automation. Please review the below figure for the level of automation and answer the following questions.



FAMILIARITY WITH THE TECHNOLOGY

1. Have you ever heard about autonomous or self-driving vehicles before participating in this survey?
   a. Yes   b. No
2. What is your general opinion regarding autonomous and self-driving vehicles?
   Even if you had never heard of autonomous or self-driving vehicles before participating in this survey, please give us your opinion based on the description you just read.

1	2	3	4	5	6	7
Very negative			Neutral			Very positive

3. According to you, which is the most attractive feature of self-driving cars? *(Please select a rank)*

   a. Safety – Reduced traffic crashes

1	2	3	4	5	6	7
Least			Neutral			Most Attractive

   b. Convenience – E.g., efficient parking

1	2	3	4	5	6	7
Least			Neutral			Most Attractive

c. Mobility – Better accessibility/mobility for passengers with disabilities/limited mobility

1	2	3	4	5	6	7
Least			Neutral			Most Attractive

d. Environment- Reduced energy/fuel consumption

1	2	3	4	5	6	7
Least			Neutral			Most Attractive

e. Amenities - More time doing other tasks during traveling

1	2	3	4	5	6	7
Least			Neutral			Most Attractive

4. How do you feel about the following types of vehicle automation? *(Please select a rank)*
   a. Cruise control/Adaptive cruise control (maintaining preset speed and ensuring safe distance)

1	2	3	4	5	6	7
Not Helpful at All			Moderately Helpful			Extremely Helpful

   b. Lane keeping assist/Lane departure warning

1	2	3	4	5	6	7
Not Helpful at All			Moderately Helpful			Extremely Helpful

   c. Automated emergency braking

1	2	3	4	5	6	7
Not Helpful at All			Moderately Helpful			Extremely Helpful

   d. Traffic jam assist (adaptive cruise control & steering at lower speed “35 mph”)

1 2 3 4 5 6 7

Not Helpful at All | Moderately Helpful | Extremely Helpful

e. Full vehicle automation

1 2 3 4 5 6 7

Not Helpful at All | Moderately Helpful | Extremely Helpful

5. As a pedestrian / bicyclist, how concerned would you be with autonomous vehicles operating on the roadway?

1 2 3 4 5 6 7

Not Helpful at All | Moderately Helpful | Extremely Helpful

INFRASTRUCTURE

1. Do you feel that the current infrastructure (markings, signs, rumble strips, etc.) need to be upgraded before the self-driving vehicles are deployed in Wyoming?

1	2	3	4	5	6	7
Strongly disagree			Neutral			Strongly agree

2. Upgrade interstate roads with smart technologies for road signs

1	2	3	4	5	6	7
Needs least			Needs moderate			Needs most

3. Upgrade interstate roads with smart technologies for pavement marking

1	2	3	4	5	6	7
Needs least			Needs moderate			Needs most

4. Upgrade interstate roads with smart technologies for merge lanes

1	2	3	4	5	6	7
Needs least			Needs moderate			Needs most

5. Upgrade two-way two-lane highways with smart technologies for road signs

1	2	3	4	5	6	7
Needs least			Needs moderate			Needs most

6. Upgrade two-way two-lane highways with smart technologies for pavement marking

1	2	3	4	5	6	7
Needs least			Needs moderate			Needs most

7. Upgrade two-way two-lane highways with smart technologies for merge lanes

1	2	3	4	5	6	7
Needs least			Needs moderate			Needs most

8. For towns and cities, what is the attention level needed for the following roadway facilities and infrastructure?

    a. Upgrade with smart technologies for road traffic lights.

1	2	3	4	5	6	7
Needs least			Needs moderate			Needs most

b. Upgrade with smart technologies for road signs.

1 2 3 4 5 6 7
Needs least — Needs moderate — Needs most

c. Ensure lane markings on city streets are visible and consistent

1 2 3 4 5 6 7
Needs least — Needs moderate — Needs most

d. Enhance intersections by providing more safety treatments and streetscapes

1 2 3 4 5 6 7
Needs least — Needs moderate — Needs most

e. Upgrade pedestrian accommodations (e.g., crosswalks)

1 2 3 4 5 6 7
Needs least — Needs moderate — Needs most

f. Upgrade parking areas by enhancing snow removal, marking and smart parking

1 2 3 4 5 6 7
Needs least — Needs moderate — Needs most

ROAD AND WEATHER CONDITIONS

Self-driving vehicles, in conjunction with highly detailed maps, rely on cameras and LIDAR to navigate. The problem is that, in conditions such as rain, snow, fog, and so on, visibility decreases, and therefore, the effectiveness of those technologies diminishes. This becomes more problematic for areas with adverse weather conditions such as Wyoming. However, there is on-going research to solve this problem.

Researchers at MIT's Computer Science and Artificial Intelligence Lab (CSAIL) are working on a different approach to self-driving technology through looking below ground, not above. They are calling on preexisting technology called localizing ground-penetrating radar (LGPR). Using it, the vehicle sends electric pulses through the ground to map the composition of the soil below the road including soil density, roots, rocks, cavities, and utility infrastructure. This mapping can then be used by other vehicles equipped with LGPR to precisely locate position relative to underground markers and landmarks. Due to these features being below ground, this technology is not affected by severe weather. This allows for the vehicle to maintain its positioning regardless of weather conditions impairing sight of visual infrastructure, GPS dead zones, or other limitations that some technologies are impacted by, such as cameras and LIDAR.

1. Given that the LGPR technology is implemented in Wyoming, would you trust the use of driverless vehicles in Wyoming's adverse weather conditions?

1	2	3	4	5	6	7
Fully Trust			Unsure			Do not trust at all

2. Do you agree that autonomous vehicles would be safer operating in adverse weather conditions with LGPR technology equipped?

1	2	3	4	5	6	7
Strongly disagree			Neutral			Strongly agree

3. Do you agree that all vehicles on the road would be safer if autonomous vehicles were equipped with this technology?

1	2	3	4	5	6	7
Strongly disagree			Neutral			Strongly agree

CAT/AVs FOR PEOPLE WITH DISABILITIES

There are various advantages of CAT/AVs for people with disabilities such as[283]:

1. Access to new employment opportunities.

2. Reduction in healthcare expenditures by providing patients with transportation services to medical appointments.
3. Increased opportunities to participate in social activities.
4. Potential benefits to pedestrians with disabilities.

1. Do you have any vision impairment/deficiency? (Loss of Central Vision, Loss of Peripheral vision, Extreme Light Sensitivity, Night Blindness, color Blindness, etc…)
   a. Yes
   b. No
   If yes, please specify_______________

2. Do you have, or have you ever had, any disability that prevents or restricts you from driving a vehicle?
   a. No known disability
   b. Vision impairment
   c. Mobility issues
   d. Hearing impairment
   e. Developmental
   f. Cognitive
   g. Others, please specify:

   If so, would you use self-driving paratransit service for your travel?

1	2	3	4	5	6	7
Never			Sometimes			Always

3. What activities do you usually engage in on a typical week and how do you usually get to those places?
   Activities, please specify:

   1. Work
   2. School
   3. Errands (i.e., grocery shopping)
   4. Appointments
   5. Sporting activities/Exercise
   6. Dining out at restaurants

7. Bars/Clubs
8. Leisure travel out of town
9. Other, please specify: ____

Transportation; please select from below:

a. Private vehicle - Driver
b. Private vehicle - Passenger
c. Carpooling
d. Public transportation
e. Motorcycle
f. Walking/cycling
g. Other, please specify: ____

4. If the need arose due to temporary disability for yourself (injury, surgery, etc.) or for family members for any reason, how likely would you be to use self-driving fixed route/curb-to-curb ADA transport service (paratransit) for travel?

1	2	3	4	5	6	7
Not at all likely			Somewhat likely			Very likely

5. How concerned would you be as a pedestrian with disability, or for those with disabilities, about autonomous vehicles operating on the roadway?

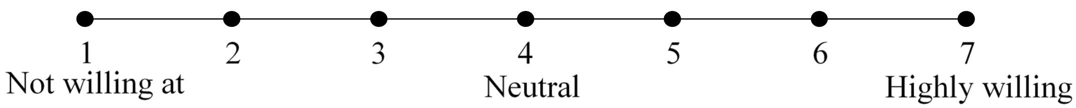
1	2	3	4	5	6	7
Not concerned			Neutral			Highly concerned

EMERGENCY MEDICAL SERVICES (EMS)

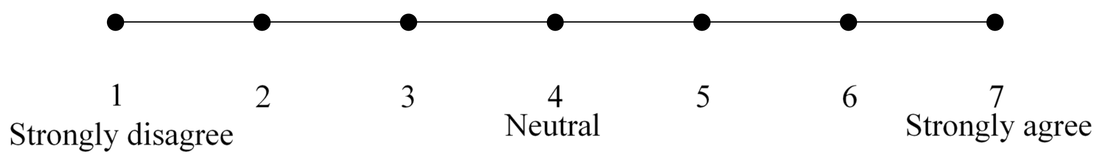
In the near future, EMS agencies are likely to adopt smart vehicle technologies. Some of these technologies, such as the collision avoidance system, are already being tested/implemented.

Imagine your next ambulance using autonomous technology to select the optimal route or parallel park at an emergency incident. The use of self-driving ambulances would also mean an extra set of hands available to take care of the patient if needed.

1. As a passenger (patient or emergency responder), how willing are you to travel in a self-driving ambulance?



2. Do you agree that self-driving ambulances will be an advantage over conventional ambulances in terms of safety, mobility, accessibility, efficiency?



AUTONOMOUS SNOWPLOWS

Some of the advantages of self-driving snowplows include:

1. Autonomous snowplows do not need to be kept in a heated place during inactivity, nor do they need to be constantly running to keep the engine from freezing up.
2. Fewer staff members are needed to operate.
3. Driver fatigue in constant snowstorms would not be a concern.
4. Communication with other autonomous vehicles on the road will help to ensure minimal, if any, crashes or conflicts.
5. Additional positioning technology such as LGPR would aid in plowing roads accurately even during extreme snowfall or snow build-up.

1. Do you agree that autonomous snowplows will reduce crashes/conflicts with other vehicles on the roadway?

1 2 3 4 5 6 7
Strongly disagree Neutral Strongly agree

2. Do you agree that autonomous snowplows will be more efficient than normal snowplows?

1 2 3 4 5 6 7
Strongly disagree Neutral Strongly agree

Privacy Risk

Connected and Automated Vehicles (CAVs) are a rich source of data that can be constantly collected by the vehicles from the high-quality sensors and cameras embedded in the vehicles. Everything from local weather data to the quality of the road las well as vehicle dynamics and routes can be gathered and shared with the appropriate parties to enhance the performance and safety of CAVs. What is your agreement level with the following statements?

1. I am concerned that CAVs will collect personal information about me.

1 2 3 4 5 6 7
Strongly disagree Neutral Strongly agree

2.I am concerned about the privacy of the information that CAVs might capture about me.

1 2 3 4 5 6 7
Strongly disagree Neutral Strongly agree

3.I suspect that my privacy could not be well protected using CAVs.

1 2 3 4 5 6 7
Strongly disagree Neutral Strongly agree

4.If you own a CAV, you would share all the collected data with the CAV manufacturer.

1 2 3 4 5 6 7
Strongly disagree Neutral Strongly agree

5.If you own a CAV, you would share anonymous data only.

1 2 3 4 5 6 7
Strongly disagree Neutral Strongly agree

6.Sharing CAV data with manufacturers would enhance the safety and operational performance of CAVs.

1 2 3 4 5 6 7
Strongly disagree Neutral Strongly agree

7. I frequently participate in information/knowledge sharing activities on Social Networking Sites (SNS)

1 2 3 4 5 6 7
Strongly disagree Neutral Strongly agree

8. I frequently share my experience or knowledge with others on SNS.

1 2 3 4 5 6 7
Strongly disagree Neutral Strongly agree

9. I frequently update information on SNS.

1 2 3 4 5 6 7
Strongly disagree Neutral Strongly agree

Cybersecurity of CAVs

Cybersecurity is the practice of protecting systems and components that govern safety from harmful attacks, unauthorized access, damage, or anything else that might interfere with safety function.

1. Cyberattacks on CAVs is a minor concern.

1	2	3	4	5	6	7
Strongly disagree			Neutral			Strongly agree

2. Manufacturers should be held liable for cyberattacks.

1	2	3	4	5	6	7
Strongly disagree			Neutral			Strongly agree

3.The CAV owner should be held liable for cyberattacks.

1	2	3	4	5	6	7
Strongly disagree			Neutral			Strongly agree

4. Increasing public awareness about Cybersecurity by providing educational campaigns can help in promoting safety for road users.

1	2	3	4	5	6	7
Strongly disagree			Neutral			Strongly agree

General Opinions

Current Technology:

Level 0 (No Automation): a vehicle with no automation (zero automation); a driver is always required to operate the vehicle and perform all the driving tasks.

Level 1 (Driver Assistance): vehicles assist the driver by taking control of one or more of the functions such as speeding, braking, steering, or accelerating; drivers still maintain overall control.

Level 2 (Partial Automation): vehicles assist the driver by combining more than one automated function from Level 1; driver still maintains overall control and must remain engaged with the driving tasks.

Future Technology:

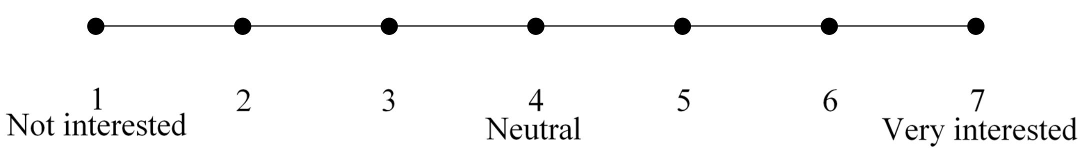
Level 3 (Conditional Automation): vehicles can operate in an automated manner in a specific area with a driver being ready to take control if needed; only occasional control by the driver will be required.

Level 4 (High Automation): vehicles can perform all driving tasks under certain conditions. Driver may have the option to control the vehicle.

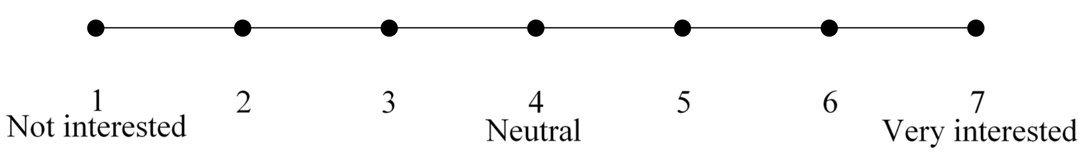
Level 5 (Full Automation): vehicles can operate in an automated manner in all areas, at all times; no driver intervention required.

Based on the information you have been given during this survey as well as your own knowledge of autonomous and self-driving vehicles, how interested are you in seeing the development and implementation of the following AV technologies?

1. Level 3 (Conditional Automation)



2. Level 4 (High Automation)



Level 5 (Full Automation)

1	2	3	4	5	6	7
Not interested			Neutral			Very interested

Autonomous and self-driving vehicles for personal/public use (Levels 3-5)

1	2	3	4	5	6	7
Not interested			Neutral			Very interested

Upgraded infrastructure

1	2	3	4	5	6	7
Not interested			Neutral			Very interested

Additional and improved charging stations for electronic and autonomous vehicles

1	2	3	4	5	6	7
Not interested			Neutral			Very interested

3. Improved driving safety and ability in adverse weather conditions for partially and fully autonomous vehicles (i.e., LGPR for vehicles of all levels of automation 0-5).

1	2	3	4	5	6	7
Not interested			Neutral			Very interested

4. Self-driving fixed route/curb-to-curb ADA transport service (paratransit)

1	2	3	4	5	6	7
Not interested			Neutral			Very interested

5. Emergency Medical Services (Self-driving ambulances, firetrucks, etc.)

1	2	3	4	5	6	7
Not interested			Neutral			Very interested

6. Autonomous snowplows

1	2	3	4	5	6	7
Not interested			Neutral			Very interested

BACKGROUND INFORMATION

1. Did you have any difficulty understanding the questions in the survey?

   a. Yes   b. Some difficulty   c. No

2. What is your gender?
   a. Male   b. Female   c. Other
3. What is your age?
   a. 16 to 24
   b. 25 to 34
   c. 35 to 44
   d. 45 to 54
   e. 55 to 64
   f. 65 or older

4. What is your highest level of education?
   a. Less than a high school diploma
   b. High school degree or equivalent
   c. Bachelor’s degree
   d. Graduate degree (Master’s/PhD)
   e. Others, please specify:
5. What is your current employment status?
   a. Employed full-time
   b. Employed part-time
   c. Retired
   d. Student
   e. Not currently employed
6. What is your household income?
   a. $0 - $24,999
   b. $25,000 - $49,999
   c. $50,000 - $74,999
   d. $75,000 - $99,999
   e. $100,000 - $149,999

f. $150,000 or more

7. Which type of driver's license do you hold?
   a. Class C – non-commercial driving license
   b. Class M – motorcycle license
   c. Class CDL – commercial
   d. None
   e. Others, please specify:
8. How frequently do you travel out of town?
   a. Every day (for work or other)
   b. Once a week
   c. Once a month
   d. Few times a year
   e. Never
9. How often do you participate in outdoor/recreational activities such as hiking, camping, skiing, etc.?

1	2	3	4	5	6	7
Never			Once or twice a			Every weekend

10. How much time per day do you use a computer/tabloid/smartphone (for any task)?

1	2	3	4	5	6	7
I do not use a computer/tabloid/smartphone			About 5 hours each			More than 8 hours each day

11. How concerned are you about your personal data being exposed on the internet?

1	2	3	4	5	6	7
Not concerned			Neutral			Highly concerned

12. How often do you pay MORE for a new service/product that is an improvement/upgrade over the current service/product that you are using?

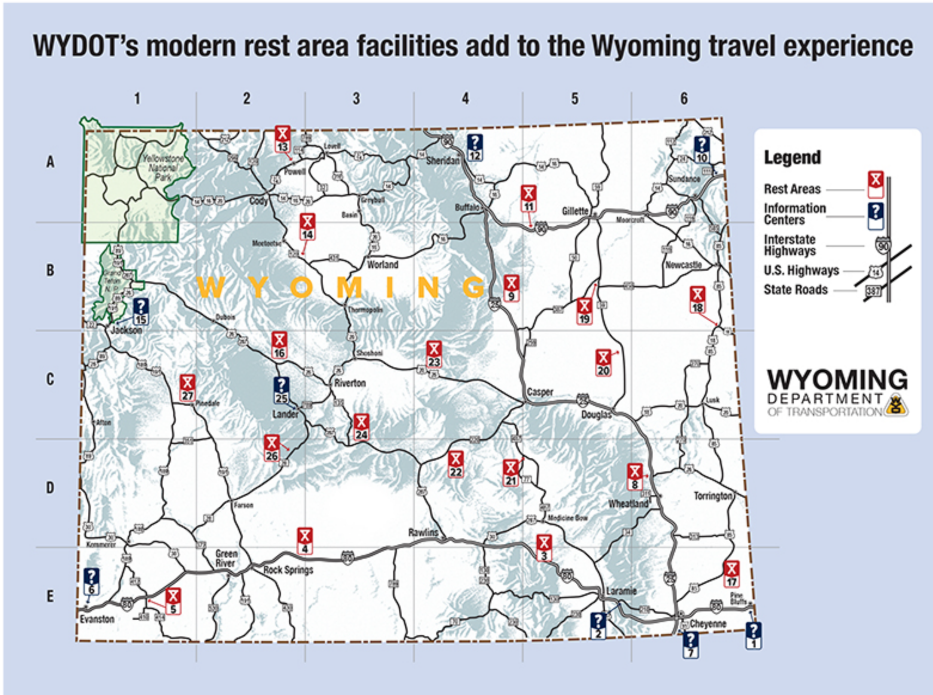
1	2	3	4	5	6	7
Never			Sometimes			Always

13. Which product would be interested in spending more money on?
    a. Household products
    b. Electronic devices
    c. Recreational vehicles
    d. Educational items
    e. All of the above

End of the Survey

Thanks for your feedback!

APPENDIX D



Wyoming's Roadside Rest Areas & Information Centers

For highways with dual or multiple route numbers, refer to the lowest route number. For example, for US 26-89-191, refer to US 26.

Information centers are staffed at least part of the year with people who can answer tourism-related questions.

Route / Location	Family Rest Room	Tourist Information	Picnic Arbors	Pet Exercise Area
I-80				
1 Pine Bluffs (E-6)*	●	●	●	
2 Summit, 9 miles east of Laramie (E-5)		●	●	
3 Wagonhound, 50 miles west of Laramie (E-5)	●		●	
4 Bitter Creek, 41 miles east of Rock Springs (E-1)	●		●	
5 Lyman, 36 miles east of Evanston (E-1)	●		●	
6 Bear River, 1 mile east of Evanston (E-1)		●		
I-25				
7 Cheyenne (E-6)		●	●	
8 Dwyer Jct., 12 miles north of Wheatland (D-6)	●	●	●	●
9 Kaycee, 46 miles south of Buffalo (B-4)	●	●	●	●
I-90				
10 Northeast, 6 miles east of Beulah (A-6)	●	●	●	
11 Powder River, 32 miles east of Buffalo (B-5)	●		●	●
12 Sheridan (A-4)	●	●	●	●
US 14A				
13 Powell (A-2)		●	●	
WYO 120				
14 Gooseberry Creek, 37 miles northwest of Thermopolis (B-2)	●		●	
US 26				
15 Jackson (B-1)		●	●	
16 Diversion Dam Jct., 37 miles west of Riverton (C-2)	●		●	●
US 85				
17 Meriden, 40 miles northeast of Cheyenne (E-6)	●		●	
US 18 & US 85				
18 Mule Creek Jct., 25 miles south of Newcastle (C-6)	●		●	●
WYO 387				
19 Wright (B-5)		●	●	
WYO 59				
20 Cheyenne River, 43 miles north of Douglas (C-5)	●	●	●	
WYO 487				
21 Shirley Basin, 42 miles north of Medicine Bow (D-4)			●	●
WYO 220				
22 Independence Rock, 52 miles southwest of Casper (D-4)	●	●	●	●
US 20				
23 Waltman, 49 miles west of Casper (C-4)		●	●	
US 287				
24 Sweetwater Station, 39 miles southeast of Lander (C-3)	●		●	
25 Lander (C-2)		●	●	
WYO 28				
26 South Pass, 43 miles southwest of Lander (D-2)	●		●	●
US 191				
27 Pinedale (C-1)		●	●	●

Figure 31 Rest areas in Wyoming. Source: WYDOT