# Impacts of Cooperative Automated Transportation on Wyoming Highway Infrastructure


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## 1. 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. Cooperative Automated Transportation (CAT), including Connected Vehicles (CVs), Automated Vehicles (AVs), and Connected/ Automated Vehicles (CAVs) have been the main focus of the automotive industry in the recent years (*Fagnant and Kockelman, 2015; NHTSA, 2016; Cottam, 2018; NOCoE, 2019*). To date, several automakers such as Tesla, General Motors, Mercedes, and Toyota, among others have already demonstrated their Highly-Automated Driving Systems (ADS). Many automotive manufacturers aim to roll out production vehicles with autonomous driving capabilities in the near future (*Miller, 2018; Litman, 2019*). According to the National Highway Traffic Safety Administration (NHTSA) and the Society of Automotive Engineers (SAE), highly automated vehicles (HAVs, e.g., SAE automation levels 3, 4 and 5) have been the main future research emphasis (*NHTSA, 2017; SAE International, 2019*). This era of cooperative automated transportation will transform people's lives in many ways. In comparison to traditional human-driven vehicles, CAT have the potential to bring about transformative safety, mobility, human productivity, fuel consumption, and environmental benefits to the surface transportation system (*Martinez-Diaz et al., 2019*). 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 CAV 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.

In view of the substantial benefits of CAT, a number of states in the U.S. have taken the initiative to enact legislation to assure a safe and well-defined framework of the implementation of CAT. According to the National Conference of State Legislatures (NCSL), 30 states in the U.S. have enacted legislation related to CAT, and Governors in 11 states have issued executive orders related to CAT (*NCSL, 2019*), as illustrated in Figure 1.

Despite of the benefits of CAT, it will not be free of problems or unexpected consequences. Below are a few of key potential downsides of Autonomous Driving Systems (ADS), which might present challenges of a successful and safe deployment of CAT:

***Technical Challenges:***

- *Infrastructure issues:* at what point should we dedicate lanes to Cooperative Automated Transportation (CAT)? Will be certain roadways/ conditions that ADS will not be permitted to travel on? State-wide deployment of enabling infrastructure for Vehicle to Infrastructure (V2I) and Infrastructure to Vehicle (I2V) communication; impact of truck platooning on structural requirements for pavements, bridges, and culverts; braking performance and sight distance variabilities and their implications on geometric design, impact of AVs on parking; maintenance and upgrade of signs and markings; and future designs of highways, streets, intersections, etc.

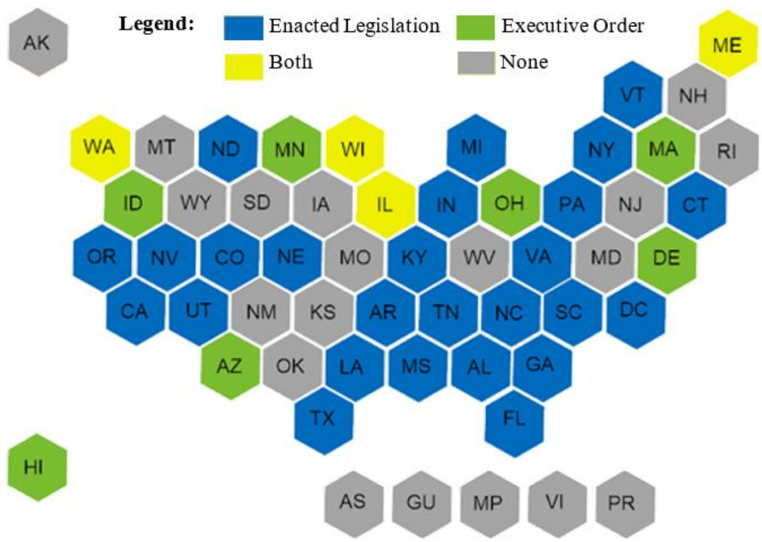


***Figure 1.*** *States in the U.S. with Autonomous Vehicles Enacted Legislation and Executive Orders (Source: NCSL, 2019)*

- *Change in traffic control devices*: how will the needs for traffic control devices change, and how will this affect other road users and non-CAT modes?
- *Transportation Systems Management and Operations (TSMO) and Intelligent Transportation Systems (ITS)*: with high AV market penetration rate, designated automated zones could be defined with much higher speeds requiring less number of and/ or narrower lanes; different demand management strategies for AVs; new performance measurements might be needed; needs for upgraded systems to ingest and manage large amount of CAV data; new risk management and cybersecurity requirements; new tolling and pricing paradigms for AVs, etc.
- *Creating and maintaining digital maps for CAT*: autonomous driving relies on a combination of detailed pre-made maps and on-board sensors to detect obstacles on the road. Creating a state-level detailed map will be a time-intensive costly process.
- *Road and weather conditions*: road and weather conditions might be unpredictable and vary from one place to another. Could CAT accurately recognize roadway markings, work zones, traffic signals when road conditions are severely deteriorated and/or affected by adverse weather conditions?
- *Interactions with other transportation modes and human-driven vehicles*: how will CAT interact with regular human-driven vehicles, pedestrians and bicyclists?

***Non-Technical Challenges:***

- *Safety and regulatory concerns*: before AVs/CAVs can be approved for testing or running on public roads, local agencies must develop AV regulations. This is a complex problem, since the safety effects of AVs/CAVs are unknown.
- *Accident liability*: who will be liable for accidents caused by AVs/CAVs? The manufacturer, the passenger, or will State DOTs, Cities and other transportation agencies also share the liability?
- *Law enforcement interaction with commercial Automated Vehicles*: how would Wyoming Highway Patrol pull over a commercial vehicle from a truck platoon?
- *Disruptions in the labor market*: will CAT replace truck, transit and taxi drivers, or support them?

- *Privacy issues*: autonomous driving requires AVs/CAVs to communicate and share data with each other; how to securely sanitize, process, share and store the massive data collected from CAT?
- *Peak hour spreading*: it is expected that the VMTs will increase because AVs/CAVs will return to their origins after passenger drop-off, and driving to the destination for passenger pick-up. How will this impact the peak hour traffic, and are we going to have peak hours in the traditional sense? Also, restrictions on the number of allowable hours of driving for commercial truck drivers might be lifted.

In short, 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 AV interactions with highway infrastructure. Therefore, it is necessary for state DOTs, municipalities, and cities to address potential impacts of CAT on surface transportation systems. In this regard, the Transportation Research Board of the National Academy of Sciences launched a forum on preparing for AVs and shared mobility in early 2018. This forum aims to facilitate the deployment of CAT-related technologies in a timely manner that informs policy to meet their long-term goals, including safety enhancement, congestion reduction, better accessibility, environmental and energy sustainability, and encouraging economic development and equity, etc. (*Kortum and Norman, 2018*). Preparing solutions to these challenges is particularly critical to the state of Wyoming, a state that has the highest car ownership in the nation, high number of low traffic volume rural two-lane highways, and mountainous freeways that are characterized by heavy inter- and intra-state freight traffic. With consideration of these features, it is expected that CAT might be more popular on Wyoming's low-volume freeways, highways and urban roads due to its nature of long trip distances and vehicle miles traveled.

Currently, Wyoming is on the forefront of one of the U.S. Department of Transportation (USDOT) transportation innovation programs for deploying and testing CV technology (*WYDOT, 2019*). Connected Vehicle is considered a constituent of fully automated driving systems. Nevertheless, currently there is a lack of a thorough understanding of Wyoming residents' perceptions of CAT, and no action regarding AV/CAV regulation and legislation has been taken in Wyoming. In practice, regulation and legislative responses to AV/CAV technology varied significantly; usually depending on the state. In view of the potential national-wide deployment of CAT, developing Wyoming AV testing regulations and safety legislation will help WYDOT to better prepare for the future of Cooperative Automated Transportation (CAT). Meanwhile, to support the future deployment of CAT in Wyoming, one of the most critical technical challenges that will be faced by the WYDOT is to ensure the infrastructures are appropriately planned, designed, and maintained, such that CAT can operate safely and efficiently. The magnitude of the adaptation needed of highway infrastructure to accommodate human and machine drivers during the progressive transition to a fully automated vehicle fleet extends a significant challenge for Infrastructure Owner/ Operators (IOOs). It is expected that AVs/CAVs' unique navigation capabilities might change, remove, or reduce the requirements for roadside signs and marking. Benefited from AVs/CAVs' advanced control system, brake reaction time could be significantly reduced in comparison with regular human-driven vehicles, which tends to call for a shorter stopping sight distance. CAT's platooning and communication technologies may also unlock possibilities for higher capacities, higher speed limits, shorter merge areas and ramp terminals, steeper grades, no or shorter climbing lanes, smaller gap acceptance for turning and crossing vehicles, and shorter turn bays at signalized intersections. In addition, the impact of truck platooning might adversely affect structural requirements for pavements and bridges due to shorter headway space and the resulting different loading schemes. State dots and local agencies should assess and regulate the size, gap spacing, of truck platoons as well as develop means to inform other road users. Other human-driven vehicles must be notified about trucks in a platoon, so they are better prepared for an upcoming exit. Other impacts on multimodal infrastructure (bike lanes and complete streets designs), need for other roadside infrastructure such as guardrails, enhancements to roadway digital infrastructure, etc. will also be assessed with a focus on rural settings. In short, new roadway design standards and traffic regulations will be required to ensure optimization of infrastructure, geometry and traffic control to accommodate CAT. The way that traffic signals operate will also need to be altered/ upgraded to enable CAT. New traffic signal warrants will be needed, as well as new operational procedures and optimization techniques. Parking needs will be impacted significantly. The AVs/CAVs will have the option to return to their origin after dropping off the passenger(s), eliminating the need for parking at certain destinations. Truck parking standards and needs might see changes due to the nature of AVs. New approaches in determining parking needs will be required, including different standards for designing parking lots and on-street parking.

To be able to keep up with an ever-changing technology of fully and highly automated vehicles and an already present conventional vehicles with myriad levels of Advanced Driver Assistance Systems (ADAS), 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 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 and parking 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.

# 2. Literature Review

## 2.1 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 AVs on public roads is almost universally illegal. Nevada was the first state to authorize the operation of AVs in 2011. By 2019, 36 states in the U.S. have either passed legislation, issued executive orders, or announced initiatives to accommodate AVs on public roads (*NCSL, 2019*). Among these states, California has been the top-ranked state in openness and preparedness for AVs. In September 2014, California introduced its AV testing regulations, which required a driver to be in the vehicle, ready to assume control of the vehicle when needed. In early 2018, the California Department of Motor Vehicles (DMV) approved regulations of testing and public use of fully AVs without drivers to operate on public roads (*California DMV, 2018*). As of 2019, California and Arizona became the first two states in the U.S. that allow AVs on public roads without drivers.

On September 2016, the National Highway and Transportation Safety Administration (NHTSA) issued updated guidance for the safe development of Highly Automated Vehicles (HAVs). The policy update was broken down into four parts: vehicle performance guidelines; model state policy; NHTSA's current regulatory tools; and, possible new regulatory actions that could be helpful in ensuring a safe deployment of HAVs (*NHTSA, 2016*). Later, NHTSA released new federal guidelines for Automated Driving Systems (ADS), which contains two general sections: Voluntary Guidance and Technical Assistance to States

(*NHTSA, 2017*). Voluntary Guidance supported the automotive industry and other key stakeholders as they consider and design best practices for the testing and safe deployment of ADSs. It contains 12 priority safety design elements for consideration, including vehicle cybersecurity, Human Machine Interface, crashworthiness, consumer education and training, and post-crash ADS behavior. Technical Assistance to States clarified and delineated federal and state roles in the regulation of ADSs. This section also provides best practices for legislatures, incorporating common safety-related components and elements regarding ADSs that states should consider incorporating into legislation. Additionally, it includes DOTs view of federal and state roles and provides best practices for state legislatures and best practices for highway safety officials.

### 2.2 Impacts of CAT on Infrastructure and Roadway Design

According to the Society of Automotive Engineers (SAE) Standard J3016 (*SAE, 2019*), six levels of driving automation (Level 0 to Level 5) were defined, as illustrated in Figure 2. Based on NHTSA's guidance, SAE automation level 3 and above ADSs will be the main future research emphasis (*NHTSA, 2017*).


***Figure 2.*** *Summary of SAE Standard J3016 Levels of Driving Automation (Source: SAE, 2019)*

It is worth mentioning that Advanced Driver Assistance Systems (ADAS) and Automated Driving Systems (ADS) are constituents of Highly- and Full Automated Vehicles; automation levels 3, 4 and 5. Nevertheless, the design of all levels of automation are considered under Operational Design Domains (ODD). ODD defines the specific operating conditions of roadway types, speeds, connectivity under which a certain level of automation is designed to safely function. Figure 3 below illustrates the various elements that may be considered when stipulating an ODD. In rural states, such as Wyoming, there are some automation features which might not function properly at certain times because of dynamic changes of ODD. For example, lane keep assist may not work properly under snow or wet pavement conditions. Moreover, the deterioration of pavement markings due to aging and snow removal operations, may affect the performance of Advanced Driver Assistance Systems that depends mainly on a camera system. Even during daytime in normal weather conditions, the sun position and the type of pavement marking might be significant factors in defining an ODD. An example of possible environmental conditions is provided in Figure 4.

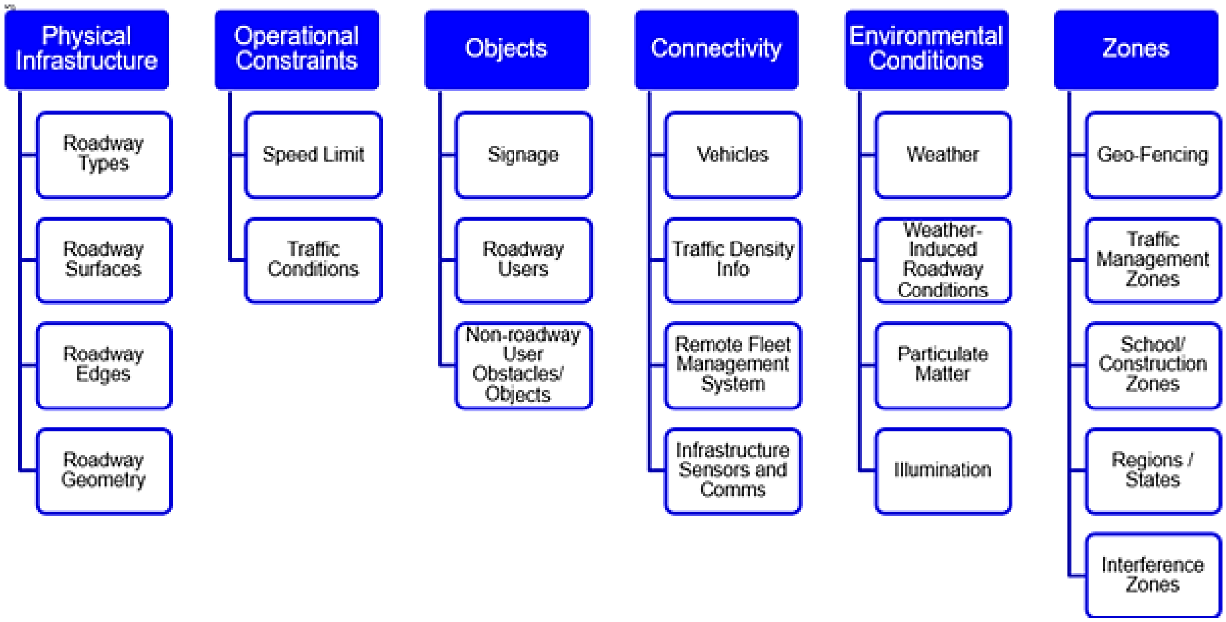


***Figure 3.*** *Conceptual Operational Design Domain (ODD) elements (Source: NHTSA (Thorn, Kimmel, & Chaka, 2018)).*

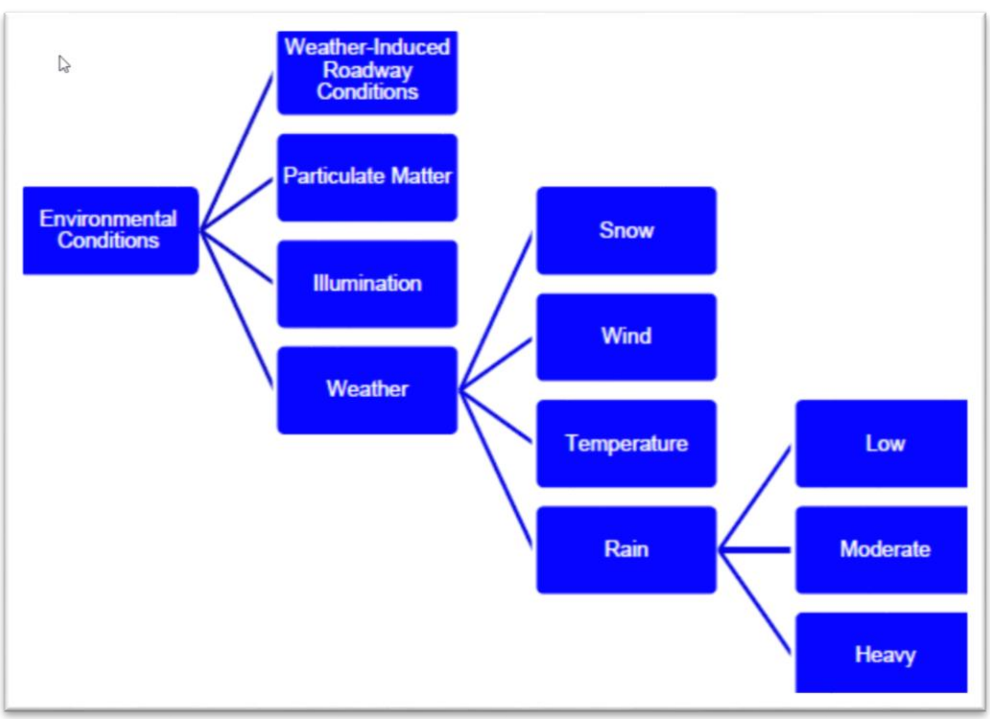


***Figure 4.*** *Example of the environmental conditions of an ODD (Source: NHTSA (Thorn, Kimmel, & Chaka, 2018)).*

CAT has the potential to significantly transform the nation's roadways. CAT 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 (*Kockelman, et al., 2017*). McDonald (*2017*), discussed the potential impacts of CVs and AVs on geometric design of roadways. It was proposed that the physical features (such as vehicle dimension) and mechanical performance of vehicle will influence the controlling criteria of roadways, such as design speed, lane and shoulder widths, horizontal and vertical curve radii as well as superelevation rates, maximum grade, stopping sight distance, etc. In addition, there might be new requirements for traffic signs, stripes, as well as other roadside safety devices; i.e., rumble strips/ stripes. Noorvand et al. (*2017*), investigated the impacts of autonomous trucks on the design and maintenance of pavement infrastructure, including rutting, fatigue cracking, and overall pavement smoothness. Simulation results suggested that autonomous trucks could reduce the pavement thickness design standards, which would reduce roadway construction and maintenance costs, particularly when the penetration of autonomous trucks is larger than 50 percent. The potential benefits stemmed from the ability to more systematically control the positioning of autonomous trucks and more uniformly use the available pavement surface. Ruhl et al. (*2018*), pointed out that AVs offer an opportunity to significantly re-share urban streets. Based on a case study in California, the authors concluded that AVs will increase the curbside passenger loading demand as well as on-street parking; therefore, it will be critical to balance passenger loading with on-street parking demands. In addition, since AVs tend to bring greater efficiencies to roadway operations, this will allow for lane reductions and complete streets features, which presented opportunities to other modes such as walking and cycling. The operation feature of AVs will also make a great impact on the design of car parking. Nourinejad et al. (*2018*), indicated that since AVs do not need to open the doors, so they can park with very little space in between. Additionally, AVs do not require parking to pick up or drop off passengers at airports and seaports. In addition, the operator can adjust signals to rearrange the AVs, which would greatly improve the efficiency of parking lots. Simulation results revealed that in comparison with traditional vehicle parking, AV parking can decrease the need for parking space by an average of 62 percent and a maximum of 87 percent.

CAT will also transform the signal control algorithms and infrastructure design standards. Aziz et al. (*2017*), identified the potential challenges and opportunities associated with CAVs based signal control deployment in terms of signal settings and infrastructure needs. It was concluded that the most challenging issues with CAV-based signal control system include: effect of market penetration of CAVs, investment for the roadside infrastructure, developing and enforcing regulation pertaining to CAV-based intersection management, fault tolerance and resistance to cyber-attacks, and traffic flow and intersection modeling accounting for CAV environment in simulation tools. While CAV-based Signal Phasing and Timing (SPaT) created opportunities such as detector free signal control schemes, dynamic intersection performance management and network-level system optimization to improve traffic operations might be challenging.

## 2.3 Social Impacts of CAT

With the progressing of CAT, concerns and debates about the impact of CAT on employment are rising. On one hand, fully automated vehicles have the potential to replace jobs of various professional drivers, and advancements in technical service and management may reduce the demand of employment in low-skill service and manual labor occupations (*Milakis et al., 2017*). On the other hand, CAT may also create new job opportunities in hardware and software development (*Milakis et al., 2017*), and service industries due to the potential increase in Vehicle Miles Traveled (VMT) (*Soteropoulos et al., 2019*). In summary, it is anticipated that CAT have the potential to transform the U.S. economy and change the structure of almost every industry (*Clements and Kockelman, 2017*).

Some representative findings regarding the social impacts of CAT are presented below. Beede et al. (*2017*), estimated that AVs would affect around 11 percent (i.e., 15.5 million) of the U.S. workers in various occupations. It was concluded that motor vehicle operators, being limited by age, education level, and transferable skills, might have difficulty finding alternative employment, especially the kind of skills required for non-routine cognitive tasks. In comparison, other on-the-job drivers usually have a more diversified set of work activities, knowledge and skills, are likely to be able to adapt to the widespread adoption of CAT. Therefore, it is necessary to keep track of the works, skills and knowledge required in these occupations to understand the extent to which AVs will serve to substitute for labor by eliminating particular jobs. Austin et al. (*2017*), indicated that though it is difficult to accurately predict the impact of CAT on the nation's economy, the number of jobs at risk could be greater than four million. On the other hand, CAT with no doubt will create new occupations, and might lead to indirect jobs due to the additional dollars that people and businesses saved from vehicle insurance, accident repairs, and car-crash medical bills. Yankelevich et al. (*2018*), indicated that AVs would necessitate a substantial change in the way that employees perform their jobs in transportation and many other sectors. In the trucking industry, AVs could supplement, rather than substitute vehicle operators, allowing freight transportation and other delivery service companies to address an existing labor shortage. While for passenger transportation, AVs are expected to displace, rather than supplement transit and especially taxi drivers. The advent of CAT is also likely to result in the creation of thousands of new jobs in engineering, data analysis, cybersecurity, and vehicle monitoring areas. This will require the acquisition of new skills and, in some cases, perhaps reimagining of what their job entails. Groshen et al. (*2018*), pointed out that considering Americans' current reliance on cars and trucks, the transition to CAT would significantly reform their lives and livelihoods. Based on historical experience and economic theory, the authors developed a framework to trace the labor market impacts of CAT. Simulations results suggested that employment disruptions will not start in large numbers until after 2030, and the introduction of autonomous cars and trucks could directly eliminate 1.3 to 2.3 million workers' jobs over the next 30 years. Participially, the impacts might be most severe for the inland states (i.e., North Dakota, Arkansas, Nebraska, Iowa, Wyoming, Mississippi, Tennessee, and South Dakota) that have disproportionate shares of heavy and tractor-trailer truck drivers (*Groshen et al., 2018*). While new jobs are expected to be created since the low travel costs of CAT would stimulate travel demands and purchases of other goods and services, indicating that the economy would eventually return to full employment after CAT-adoption layoffs (*Groshen et al., 2018*). To mitigate the losses to workers, it is necessary to strengthen existing policies or propose new workforce development systems such as unemployment insurance system, one-stop centers to aid unemployed workers, training grants, community colleges, etc. In addition, the design of new CAT-related jobs needs to take advantage of the skills that workers in the disrupted occupations already have, such as truck drivers might have skills well-suited for traffic monitoring, truck maintenance, or remotely piloting convoys of trucks.

Nevertheless, successful deployment and operation of CAT system depend largely on a knowledgeable, trained, and skilled workforce to support them (*Lockwood and Euler, 2016; Cummings, 2017*). It is undoubted that the current and future transportation workforce must be advanced and evolved (*Noch, 2018; FHWA, 2018*). Hayeri et al. (*2015*), indicated that as CAT begins to replace regular vehicles, Automated Highway Systems (AHS) will begin to replace current roadways and more electronic assist features and communication technologies will begin to appear in vehicles. To ensure transportation workforce keeps up with the changes in automobile technologies, academic institutions must become part of the changes. A successful path towards automated driving systems would result in changes to educational curriculums of local trade schools, community colleges and universities, updates to tests and new certifications offered by professional organizations, and changes in the driver licensing procedure. Specifically, academic institutions should place more emphasis on electronics and computer science when educating automotive technicians in order for students to be knowledgeable on the electronic components and advanced computer systems which would be equipped in AVs/CAVs. Leonard et al. (*2016*), indicated that the development, integration and deployment of innovative vehicle technologies requires a well-trained and capable workforce to create, embrace, and use them. Therefore, transportation professionals need to adapt to the continuous evolution of vehicle technologies, and digital infrastructure. Universities as well as other certificate programs must also be prepared to update their engineering curricula to satisfy the emerging needs of the related technologies for transportation (*Leonard et al., 2016*). Another research performed by Cummings (*2017*) emphasized the importance of interdisciplinary research for CAT, since the operation and maintenance of CAT call for a large number of high-skilled engineers from a variety of disciplines such as electrical engineering, mechanical engineering, computer engineering, and artificial intelligence, etc. While the demand for these disciplines exceeds the supply from universities and colleges, it is necessary for universities to adapt to these increasing demands; scholarships and incentives from government agencies and other foundations should be provided to CAT-related new programs. Research conducted by the Workforce Intelligence Network (WIN) for southeast Michigan revealed that the greatest demand for workers with CAT skills was for those in information technology, information security, and computer systems (*WIN, 2017*). For these high-technology occupancies, workers must have higher educational attainment at a minimum of bachelor's level and/or with several years of experience. This creates a new opportunity for community colleges and universities to provide the baseline training or upskilling necessary for workers in the CAT area. To move forward the workforce of CAT, WIN recommended that current workers in CAV-related occupations who lack CAV-related skills must start to cross-train and develop related skills in order to remain competitive. Meanwhile, community colleges, workforce boards, universities and 4-year colleges must be strengthened to enhance the training provided to and received by the current and future workforce (*WIN, 2017*). Similarly, Fong and Olanie (*2018*), stated that jobs created as a result of CAT will be related to the development and maintenance of the new technologies, indicating that automobile and Information and Communication Technologies (ICT) companies are in need of skilled engineers and programmers, which usually require a bachelor's degree or higher. This creates an opportunity for higher education institutions to enhance their existing curricula in the areas of specific value to CAT, which will eventually benefit state DOTs and related industries to recruit well-trained and skilled employees.

With consideration of the changes of driving tasks and vehicle performance, there is a need to provide appropriate training to both CAT drivers and other road users on the capabilities, limitations, and correct operation of CAT (*Zmud et al., 2017*). In addition, the increasing adoption of CAT is expected to result in changes to driver licensing requirements. Such as Hayeri et al. (*2015*) recommended that driver licensing and driving testing criteria for AVs should be updated to assure the driver is familiar with all standard electronic assist features and align with training requirements to safely operate highly automated vehicles. This is particularly critical for Level 3 AVs, since Level 3 AVs requires human input, therefore a special driver's license might be required. Nevertheless, for Level 4 and 5 AVs, the authors argue that driver licensing requirements would become increasingly obsolete due to the reduced requirement for input from human drivers. Considering the fact that HAVs (Level 4 automation) and Full AVs (Level 5 automation) will not occupy the vehicle market in the short term, Cunningham et al. (*2016*), indicated for the current driver training, a fundamental human factors issue that will need to be addressed, is the requirement for drivers to resume manual control of Level 3 AV when it issues a takeover request. For safe operation of Level 3 AVs, drivers will also need to acquire knowledge and training in order to understand the capabilities and limitations of the AV technology. With adequate training on the capacities and limitations of AVs, it will help to normalize drivers' trust and reliance on AVs. Zmud et al. (*2017*), concluded that CV technologies, which provide drivers with enhanced Traveler Information Messages (TIMs), will not significantly change the current driver training or licensing requirements. In comparison, AV technologies, which take over part or all of a vehicle's operation tasks (e.g., steering, speed control, lane-keeping, lane-changing, braking, etc.), will result in considerable impacts on vehicle operation, and accordingly, the requirements for driver training and licensing. These effects are particularly crucial when ADS is the default vehicle operating mode and cannot be easily deactivated by the driver. In this regard, it is necessary to assess drivers' physical, perceptual, and decision-making skills that will be needed to interact with each level of vehicle automation, which will eventually be used to guide the development and implementation of new driver training and licensing programs. Ahmed et al. (*2019*) developed a driver training program to train snowplow truck drivers from the Wyoming Department of Transportation (WYDOT) and commercial truck drivers from various trucking firms with the system components of Wyoming CV system and hands-on operation of CVs in a simulated environment. This pioneering study, to some extent, laid a foundation for the future development of driver training programs on different levels of AVs.

## 2.4 Public Perception and Acceptance of CAT

To date, a number of studies have been conducted to investigate public perception of CAT and identify factors that affect the acceptance of CAT. In 2014, the University of Michigan Transportation Research Institute (UMTRI) examined public opinion regarding autonomous driving technology in three major English-speaking countries: the U.S., the U.K., and Australia (*Schoettle and Sivak, 2014*). It was found that through respondents in the U.S. expressed high levels of concern about riding in vehicles equipped with autonomous driving technology, such as data privacy, interaction with regular human-driven vehicles, performance of CAT, etc. However, they felt positive about self-driving vehicles, have optimistic expectations of the benefits, and generally desire autonomous driving technology when it becomes available. Kyriakidis et al. (*2015*), conducted a worldwide internet-based survey to investigate user acceptance, concerns, and willingness to buy partially, highly, and fully AVs. Overall, a large portion (69%) of respondents believed that fully automated driving would reach a 50% market share by 2050. A number of concerns were revealed, mainly regarding software hacking/misuse, safety, legal, and data transmitting issues of automated driving. In addition, respondents from high-income countries are particularly expressed concerns about the personal data security issues. Bansal et al. (*2017*), proposed a simulation-based fleet evolution framework to forecast Americans' long-term (year 2015-2045) adoption levels of AV technologies under different scenarios. Annual drops in technology prices, annual increments in Americans' Willingness To Pay (WTP), and changes in government regulations were used to assess public opinions of AVs. Buckley et al. (*2018*), employed driving simulator approach to explore drivers' responses to the experience of AVs. Findings from participant interviews revealed that financial concerns, reliability of AV system, benefits to mobility and secondary task performance, as well as hacking and privacy issues were important factors affected their intentions to drive or purchase a fully AV. For truck drivers' perception of autonomous driving, a questionnaire-based study conducted by Richardson et al. (*2017*) indicated that both truck drivers' and fleet managers' top concerns regarding autonomous driving were legal liability issues and the general safety and reliability of such technology. Truck drivers were concerned about reduced driving pleasure as well as the stability of their occupation; fleet managers favored the positive effects in economic efficiency, profitability, safety, fuel consumption and possible secondary tasks. In addition, it was found that the majority of truck drivers did not have a clear idea of autonomous driving systems, while managers were worried about their drivers' attitudes towards autonomous driving.

In summary, it was found that safety, efficiency, cost, and liability issues were among the top barriers to public acceptance of CAT. Nevertheless, the acceptance of CAT in Wyoming, a state that has the highest car ownership in the nation and a large number of low traffic volume rural two-lane highways and mountainous freeways is still unknown.

# 3. Study Benefits

Vehicle and highway automation is posing new challenges for transportation agencies. To embrace the era of autonomous driving, a thorough understanding of the impacts of CAT on Wyoming highway infrastructure, research needs and challenges that will be faced during the future deployment of CAT in Wyoming is critical to the Wyoming DOT, municipalities, and cities. This study will help in early addressing and mitigating the potential adverse effects of CAT on the Wyoming's surface transportation system. This will be conducted by synthesizing the research and practice needs and challenges for the state-wide deployment of AVs in Wyoming, and provide WYDOT with recommendations on the regulation and policy development, infrastructure design and operations, upgrades of traffic management strategies, upgrades of regional transportation planning models, and cybersecurity of data management, which will support WYDOT to safely and efficiently integrate CAT into the road network in Wyoming. The primary outcome of this study will be a synthesis of state of the art and practice related to CAT, which will recognize the current state of research and practice, technologies, implementations, potential gaps and problems that need to be addressed in near to long term. Another important outcome of the study will be a comprehensive analysis of the factors that affect Wyoming residents' perception and acceptance of CAT, which will provide WYDOT insights regarding the barriers to the deployment of CAT in Wyoming. In addition, this study will have a considerable significance for the new USDOT 2018 - 2022 strategic goals: safety, infrastructure, innovation and accountability. Since this study will assist WYDOT with developing strategies to preserve infrastructure and thus increase its efficiency.

# 4. Statement of Work

## 4.1 Overview of Research Tasks

The proposed research will concentrate on identifying the challenges involved in the state-wide development of Cooperative Automated Transportation (CAT). This will be achieved through several tasks. First, the state-of-the-practice of existing national and state level regulations and legislations related to AVs/CAVs will be reviewed and synthesized. The research team will perform a literature review of the impacts of CAT on the design and maintenance of the roadway infrastructure and traffic control devices, workforce development, changes in travel demands and vehicle miles traveled (VMT), policy and planning actions for state and local transportation agencies, regional transportation planning and modeling tools, etc. (*NCHRP, 2019; NOCoE, 2019*). On-line survey questionnaires will be developed and distributed to collect Wyoming residents' perception of CAT and autonomous driving, and determine the factors that affect the acceptance of CAT in Wyoming. Eventually, the research team will provide recommendations to WYDOT on the impacts of Connected and Automated Vehicles 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. In addition, the research team will provide WYDOT insights into Wyoming residents' perception of CAT, as well as Wyoming's needs for public/ personal transit and inclusion of autonomous transit vehicles for seniors.

Expert interviews will be conducted with all WYDOT departments and selected cities in Wyoming to identify current gaps and their expectation on how CAT would impact them and collect their feedback about what the USDOT, FHWA, AASHTO, TRB, NCHRP, and the CAT Coalition recommendations on how state DOTs and local agencies should be prepared for CAT. This will help to early mitigate potential adverse impacts of CAT. Finally, two workshops will be provided to WYDOT staff, which will present the identified critical impacts of AVs on infrastructure (i.e., Physical Infrastructure of pavements, bridges, culverts; Traffic Control Devices and Roadside Infrastructure; Transportation Systems Management and Operations (TSMO) and Intelligent Transportation Systems (ITS); Underserved Communities), research gaps that are mostly needed for Wyoming with its rural nature and long distance driving, and provide WYDOT with a guideline and a roadmap to encourage safe and efficient deployment of CAT in Wyoming.

The proposed research will consist of ten tasks, as listed in Figure 5 below. Detailed descriptions of each task are presented below.

## 4.2 Detailed Tasks

### *Task 1: Recommendations of Wyoming AV Regulations and Legislations*

In September 2017, the National Highway and Transportation Safety Administration (NHTSA) released new federal guidelines for Automated Driving System (ADS). By far, the majority of states in the U.S. have enacted legislation or issued Governor executive orders related to AVs to accommodate the testing and deployment of AVs on public roads. This research will conduct a thorough review of the exiting national and state level regulations and legislations related to autonomous driving and AV crash reporting system. The review will synthesize the state-of-the-practice reports and working papers delivered by the National Cooperative Highway Research Program, USDOT Automated Vehicles Activities, FHWA Next Generation Traffic Management Systems, AASHTO Cooperative Automated Transportation (CAT) Coalition, etc. Based on the literature review, and with consideration of the unique transportation features and potential policy barriers in Wyoming, recommendations will be provided to WYDOT and other stakeholders to develop Wyoming AV regulations and legislations. The recommendations will also provide risk management strategies for pilot on-road testing, and clarify federal, state, and local responsibilities to ensure safety prior to full deployment of CAT. In addition, the recommendations will include an updated crash reporting system, which will contain both crash data collection (including crash type and severity, prevailing traffic and weather conditions, cause(s) and liability of crash, etc.) and safety performance analysis features. It is expected that updates in crash reporting system will aid in performance measurements and evaluation of autonomous driving technologies.

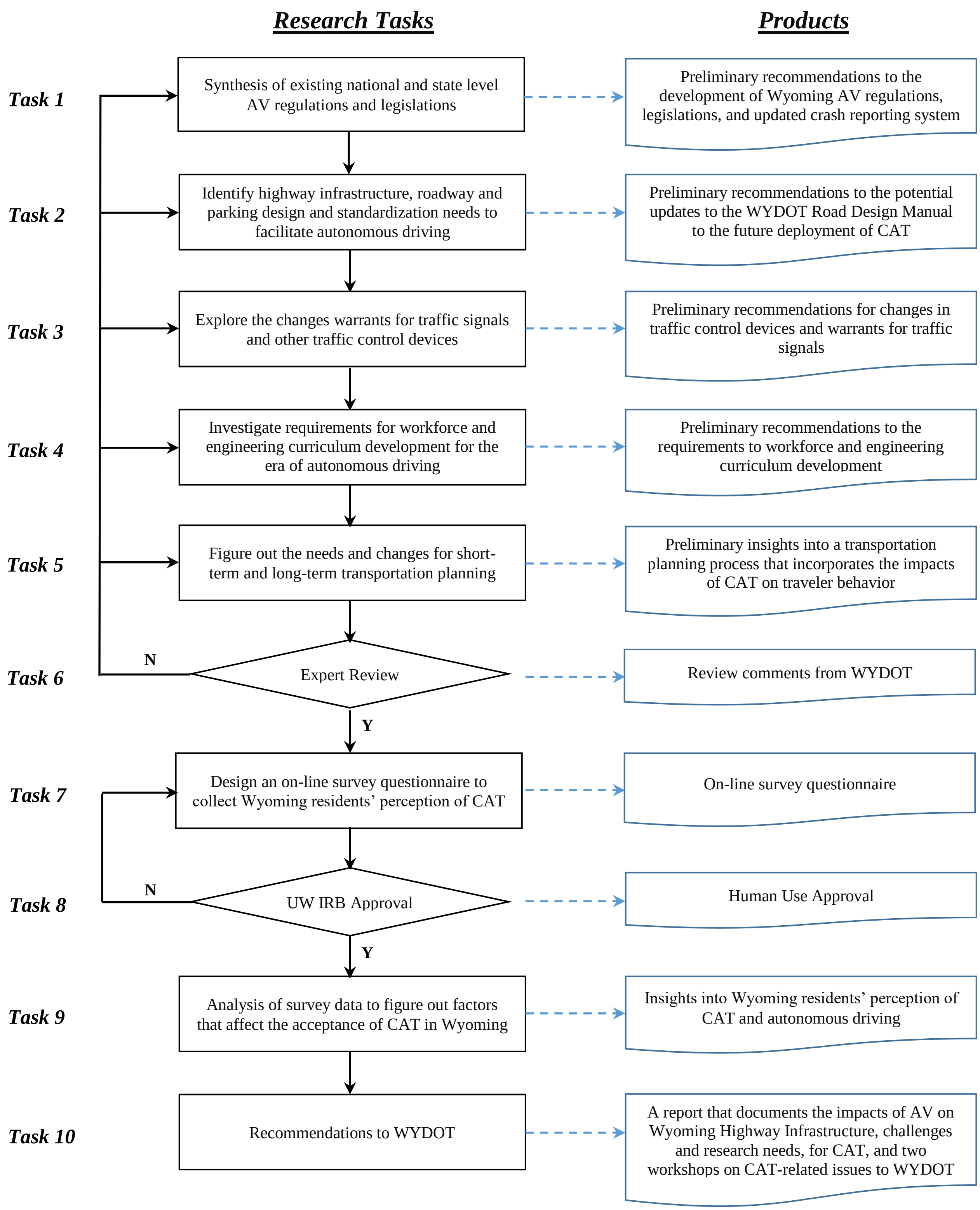


***Figure 5.*** *Overview of the Proposed Research Tasks and Expected Products*

### *Task 2: Identify the Impacts of CAT on Roadway Design and Infrastructure Requirements*

This task will, based primarily on the review of literature and interviews with WYDOT staff/ engineers, identify infrastructure, roadway and parking design and standardization needs to facilitate autonomous driving. Specifically, this research will discuss infrastructure design and standardization needs to facilitate vehicle and highway automation, such that CAT can operate safely and effectively. In addition to the design standards on interstate freeways, this study will focus on the passing lane design for Wyoming's low-volume two-way two-lane highways. It will highlight the implications of truck platooning applications and truck automation for traffic operations and the design and maintenance of roadway infrastructure. This task will also explore the standards for designing parking lots for AVs/CAVs, since AVs/CAVs will have the option to return to their origin after dropping off the passenger(s), eliminating the need for parking at certain destinations. Expected product from this task is recommendations to the potential updates to the WYDOT Road Design Manual to ensure optimization of infrastructure, geometry and traffic control to accommodate the future deployment of CAT.

### *Task 3: Explore the Impacts of CAT on Traffic Control Devices*

CAT will also change the way of traffic signals operation; in this regard, new warrants will be needed, as well as new operational procedures and optimization techniques. This task will review the state-of-the-art of the potential updates in traffic control devices and traffic signal warrants, as well as computational techniques for traffic signal system optimizations. The needs for other traffic control devices will be changed significantly, with many signs and pavement markings becoming obsolete. The corresponding DOT manuals will need to be rewritten and updated. Based on the literature review and the anticipated operational changes, the research will identify further research needs to understand these types of challenges, and provide recommendations for changes in traffic control devices and warrants for traffic signals.

### *Task 4: Investigate the Impacts of CAT on Workforce and Engineering Curriculum*

This task will explore the medium- to long-term impacts of CAT on the workforce and changes needed for engineering curriculum for the era of autonomous driving. CAT will create new job opportunities that will, to some extents, replace jobs eliminated by autonomous driving. In addition, CAT, particularly shared mobility, has the potential to bring impacts to taxi, transit, and car rental industries. This task will investigate the scale and timing of these impacts, and evolution of worker skill requirements as well as future engineering curriculum development. A pilot survey will be conducted at the University of Wyoming and the community colleges in Wyoming to investigate the existing changes of curriculum of civil engineering, mechanical engineering, electrical engineering, computer science, etc. This task will also investigate potential safety issues during the transition to highly automated vehicle, such as driver training on AV capabilities. It is expected that this task would assist policymakers in weighing AV regulations and support academic institutions and technical institutes in Wyoming to cope with the rapid pace of the evolution of CAT.

### *Task 5: Updated Transportation Planning Models*

This task will identify how CAT will change the state's short-term and long-term transportation planning models, and investigate how the traditional four-step transportation planning process accommodate the changes in travel behavior and land use. For instance, will CAT encourage more sprawl development, thus resulting in more VMT? What are the impacts of shared mobility on VMT? How will shared mobility affect the demands of taxies and rental cars? Potential modal shifts to or away from transit vehicles, and planning for rural areas.

### *Task 6: Expert Review*

Since this study aims at providing transportation planning-related policy recommendations to WYDOT, active interactions between the research team and WYDOT project managers and stakeholders from various divisions will be of a significant importance. Expert review of the preliminary findings and insights will be a powerful tool to collect independent opinions on the research needs, and examine whether the recommendations align with WYDOT's requirements. Expert review will include both presentations on the regular project progress meeting and formal review of working papers. The experts will be selected from Wyoming DOT as well as the USDOT as necessary.

### *Task 7: Design of Online Survey Questionnaire*

In light of the preliminary literature review on the aforementioned six tasks and the review comments from WYDOT experts, this research will design an on-line survey questionnaire to collect Wyoming residents' perception of CAT and autonomous driving. The survey will collect 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 will measure 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 will be informed that they would need approximately 10 to 15 min to complete the survey. The survey will primarily focus on Wyoming residents, while people who has good driving experience in Wyoming will also be considered as potential candidates. A minimum of 500 samples is expected to be collected. For respondents who successfully complete the survey, they will be provided a chance of drawing a lottery with appropriately 20 percent probability to win a $25 electronic Amazon gift card.

### *Task 8: Human Use Approval*

The principle investigator understands that any activity conducted as part of this study should minimize the risk to human participants, ensure participants consent and fully inform them of the possible risk associated with the research, and endorse equity and justice to all participants. The Office of Research and Economic Development at the University of Wyoming (UW) is responsible for the administration of research ethics. The PI will work with the University of Wyoming Institutional Review Board (IRB) to get approvals to use human subjects in the survey questionnaire. The IRB committee is composed of a diverse academic and scientific disciplines, as well as from the public. The approval procedure conforms to the US Department of Health and Human Services (HHS) regulations and policies for the protection of human subjects' rights and welfare.

For the purpose of this task, the principle investigator will develop an IRB proposal that contains a description of the purpose of the research project, description of human subject participants, recruitment procedure, number of participants, incentive to be provided, expected questions, time needed to complete the survey, participation termination process, etc. The IRB proposal will explain the procedures of protecting the privacy and confidentiality of the participants (e.g., how, where, and for how long the data will be stored, who will have access to the data, and other confidentiality issues). Risks to subjects should be described in detail of any reasonably foreseeable risks, such as discomfort or embarrassment with survey or interview questions.

#### *Task 9: Identify Factors that Affect the Acceptance of CAT in Wyoming*

Based on the survey questionnaire data, descriptive statistics (i.e., means, medians, standard deviations, and frequencies) will be calculated for each of the explanatory variables. In addition, statistical modeling will be employed to calculate the correlation coefficients between the variables and public perception of CAT, and figure out factors that affect the acceptance of CAT and barriers to the deployment of CAT in Wyoming.

#### *Task 10: Recommendations to WYDOT*

The final task of this research will provide WYDOT insights on the magnitude of the impacts of Automated Vehicles on Highway Infrastructure, and plot recommendations on the policies and planning strategies related to the USDOT's strategic goals. The recommendation will include: the development of Wyoming AV regulations, legislation, as well as updated crash reporting system, the potential updates to the WYDOT Road Design Manual to accommodate the future deployment of CAT, the requirements to workforce and engineering curriculum development, changes in traffic control devices and warrants for traffic signals, and insights into Wyoming residents' perception of CAT and autonomous driving. In addition, the research results will benefit both the scientific community and authorities responsible for traffic safety and decision-making, and will be a key to ensure the least adverse effects of the emerging autonomous driving technologies on the safety of road users in Wyoming.

## 5. Work Plan and Implementation Process

### 5.1 Project Kickoff Meeting

A kick-off meeting shall be scheduled to occur within the first 30 days of execution by the University of Wyoming. The preferred method for the kick-off meeting is via teleconference or video conference. At minimum, the project manager and the principal investigator will attend. The WYDOT Research Center staff must be advised of the meeting and given the option to attend. Other parties may be invited, as appropriate. The subject of the meeting will be to review and discuss the project's tasks, schedule, milestones, deliverables, reporting requirements, and deployment plan. A summary of the kick-off meeting shall be included in the first progress report.

### 5.2 Deliverables

Quarterly progress report will be submitted. In addition, any major achievement, i.e., the completion of tasks will be reported to the project managers. Draft final report and a final report incorporating the project managers' comments and corrections will be submitted at the end of the project.

#### *5.2.1 Progress Reports*

The University of Wyoming research team will submit quarterly progress reports to the WYDOT Research Center. The first report will cover the activity that occurred in the 90 days following the issuance of the task work order.

### *5.2.2 Draft Final Report*

The Draft Final Report is due 90 days prior to the end date of the task work order. The draft final report will be submitted to the WYDOT Research Center. It should be edited for technical accuracy, grammar, clarity, organization, and format prior to submission to the WYDOT Research Center for technical approval.

### *5.2.3 Final Report*

Once the draft final report has been approved, the University of Wyoming research team shall prepare the final report. The UW research team will email the final report in PDF as well as MS Word format.

### *5.2.4 Project Closeout Presentations*

The findings of this study will be presented to the WYDOT Research Center at the conclusion of the project.

## 6. Timeline and Budget

The study will be performed in 24 months after the Notice to Proceed (NTP). The project will be led and supervised by Dr. Ahmed and Dr. Yang, and one graduate student will be assigned to different tasks throughout the project. As shown in Table 1, the total cost of the project is $149,809. The total cost will cover all tasks listed above and illustrated in Table 2 including the literature review, travel, workshops, as well as technology transfer. In addition, the total 2 years cost will cover the salaries of one full-time MS student for 4 semesters, 6 months salary for one postdoc, and two months salary for one faculty member over the two years project period. The PIs will be submitting a proposal to Mountain-Plains Consortium (MPC) for additional funding for this study.

## 7. Technology Transfer

The research results will be disseminated through technical paper publications and presentations in academic venues and press releases using media outlets. The technology transfer activities in this project will benefit both the scientific community and authorities responsible for decision-making. The research team will seek input from other interested parties to improve upon the study design and methodology. WYDOT staffs will be involved through all phases of the research.

## 8. Data Management Plan

A Data Management Plan (DMP) is attached to this proposal. The plan provides a description of the nature, scope, and scale of data that will be collected during the course of the project. The plan provides information on how the data will be collected, shared, where the data will be housed, who will have access to the data, and any backup strategies that will be implemented. Since this project will collect human subjects' data, the University of Wyoming Institutional Review Board will review the DMP on how the research team will protect the privacy, security, and confidentiality of the subjects.

***Table 1:*** *Project Budget*

| Budget Year 1: 2019-2020 | | |
|---|---|---|
| **Impacts of CAVs on Wyoming Highway Infrastructure** | | |
| CATEGORY | Budgeted Amount from WYDOT | Notes |
| Faculty Salaries | $9,917 | 1-month salary for 1 PI |
| Administrative Staff Salaries | $0 | |
| Other Staff Salaries | $15,000 | 3-month Postdoc salary |
| Student Salaries | $16,104 | 1 MS student for year 1 |
| Staff Benefits | $13,229.56 | |
| **Total Salaries and Benefits** | **$54,251** | |
| | | |
| Student Support Other Than Salaries | $9,784 | Tuition/No indirect |
| Permanent Equipment | | No indirect |
| Expendable Property, Supplies, and Services | $4,500 | 1 Workshop |
| Domestic Travel | $2,500 | |
| Foreign Travel | $3,000 | |
| Other Direct Costs (specify) | $0 | |
| **Total Other Direct Costs** | **$19,784** | |
| | | |
| F&A (Indirect) Costs | $12,850 | 20% WYDOT |
| **TOTAL COSTS for 1st Year** | **$86,885** | |
| **Budget Year 2: 2020-2021** | | |
| CATEGORY | Budgeted Amount from WYDOT | Notes |
| Faculty Salaries | $9,917 | 1-month salary for 2 PI |
| Administrative Staff Salaries | $0 | |
| Other Staff Salaries | $15,000 | 3-month Postdoc salary |
| Student Salaries | $6,039 | 1 MS student for year 2 (1 Semester) |
| Staff Benefits | $12,726.31 | |
| **Total Salaries and Benefits** | **$43,682** | |
| | | |
| Student Support Other Than Salaries | $4,506 | Tuition/No indirect |
| Permanent Equipment | $0 | No indirect |
| Expendable Property, Supplies, and Services | $4,500 | 1 Workshop |
| Domestic Travel | $500 | |
| Foreign Travel | $0 | |
| Other Direct Costs (specify) | $0 | |
| **Total Other Direct Costs** | **$9,506** | |
| | | |
| F&A (Indirect) Costs | $9,736 | 20% WYDOT |
| **TOTAL COSTS for 2nd Year** | **$62,925** | |
| | | |
| **Total 2-Year Budget** | **$149,809** | |

***Table 2:*** *Project Schedule*

| Research Task | Month | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| **Task 1** | | | | | | | | | | | | | | | | | | | | | | | | |
| Wyoming AV Regulations and Legislations | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | | | | | | | |
| **Task 2** | | | | | | | | | | | | | | | | | | | | | | | | |
| Impacts of CAT on Roadway Design and Infrastructure | | | | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | | | | | | | | | | |
| **Task 3** | | | | | | | | | | | | | | | | | | | | | | | | |
| Impacts of CAT on Traffic Control Devices | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | | | | | | | |
| **Task 4** | | | | | | | | | | | | | | | | | | | | | | | | |
| Impacts of CAT on Workforce and Engineering Curriculum | | | | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | | | | |
| **Task 5** | | | | | | | | | | | | | | | | | | | | | | | | |
| Updated Transportation Planning Models | | | | | | | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | |
| **Task 6** | | | | | | | | | | | | | | | | | | | | | | | | |
| Expert Review | | | | | | | ■ | ■ | ■ | | | | | | | ■ | ■ | ■ | | | | | | |
| **Task 7** | | | | | | | | | | | | | | | | | | | | | | | | |
| Online Survey Questionnaire | | | | ■ | ■ | ■ | ■ | ■ | ■ | | | | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | |
| **Task 8** | | | | | | | | | | | | | | | | | | | | | | | | |
| Human Use Approval | ■ | ■ | ■ | | | | | | | ■ | ■ | ■ | | | | | | | | | | | | |
| **Task 9** | | | | | | | | | | | | | | | | | | | | | | | | |
| Factors Affecting the Acceptance of CAT Deployment in Wyoming | | | | | | | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | | |
| **Task 10** | | | | | | | | | | | | | | | | | | | | | | | | |
| Recommendations to WYDOT | | | | | | | | | ■ | ■ | ■ | | | | | | | | ■ | ■ | ■ | | | |
| **Documentation and Deliverables Schedule** | | | | Quarter Reports | | | Quarter Reports | | | Quarter Reports | | | Quarter Reports | | | Quarter Reports | | | Quarter Reports | Draft Final Report | | | Final Report | Final Report |

Quarter Reports   Draft Final Report   Final Report

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