NCHRP 20-102(19)
Update AASHTO's Connected Vehicle/ Automated Vehicle Research Roadmap

Task 2 Report
Year 1 – Catalog of Research Topics

Prepared for
National Cooperative Highway Research Program (NCHRP)
Transportation Research Board of
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Disclaimer

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1. INTRODUCTION

Connected and automated vehicle technologies are fast advancing and are expected to transform the transportation landscape. It is expected that they can improve roadway safety, reduce congestion and its associated costs, and improve land use and the environment. While connected vehicles (CVs) and automated vehicles (AVs) are two separate categories of vehicles, several studies indicate that convergence of these technologies, leading to connected and automated vehicles (CAVs), could potentially gather benefits of both and lead to a safer and more efficient transportation system.

The U.S. Department of Transportation (USDOT), industry, and research institutes have led a wide range of research and development (R&D) activities that focused on enhancements in communications and vehicle technologies. These activities led to the development of several CV applications that have already moved from research to deployment phases. The expected benefits of these technologies have led some state and local departments of transportation (e.g., Arizona, California, Florida, Michigan, Minnesota, New York, Virginia) to engage in prototyping, testing, and evaluating CV technologies. Several states and metropolitan areas are pursuing the USDOT-sponsored CV Pilots and leveraging the lessons learned to enhance their own CV implementations [1].

In addition, automobile manufacturers and suppliers and large technology firms (such as Google and Apple) are advancing automated vehicle technologies that progressively reduce dependence on drivers. The Society of Automotive Engineers define levels of automation (levels 1 through 5) based on the driving load distribution between the driver and the vehicle. As the level of automation in the marketplace evolves from current SAE Level 2 to Level 4 and the synergies between AVs and CVs become more obvious, future vehicles are expected to fully monitor the road conditions and perform many of the safety-critical driving functions, leading to significant improvements in safety and efficiency [2].

Moreover, the sharing economy has influenced numerous sectors of the economy including finance, logistics, last-mile delivery, hospitality, and transportation. Technology, mobility, and social trends are also changing the way people travel and consume resources. These trends have contributed to the rise of innovative transportation services, such as shared and on-demand mobility [3].

The emergence of safer, more efficient CAVs will fundamentally change the way federal, state, and local agencies will plan, operate, maintain, and regulate the transportation system and impact future transportation infrastructure investments. These agencies must understand the impact of CAV technologies on the systems they manage, as well as the effects of the agencies' policy, planning, and regulation; infrastructure design; and operations on technology development, adoption, and life-cycle costs. In addition, fundamental changes in the relationships among mobility providers, consumers, technology and service providers, and public agencies may necessitate public-private collaboration to fully capitalize on the opportunities presented by automation [4].

Thus, a coordinated research program that can anticipate and address the needs of state and local transportation agencies and supporting organizations, such as the American Association of State Highway and Transportation Officials (AASHTO), in this changing landscape is critical. A broad range of issues that must be addressed include:

- Standardization (e.g., roadside signs, technologies, etc.);
- The impacts of regulation on innovation;
- Reduced infrastructure life cycles (in the context of information technologies);
- Safety and liability;
- Cybersecurity;

- Privacy protection;
- Impacts on public agency workforce;
- Data sharing, standards, access, and management; and
- New forms of vehicle ownership and access.

Consequently, the National Cooperative Highway Research Program (NCHRP) initiated the program 20-102 to assess the impacts of CVs and AVs on state and local transportation agencies. The program's objectives are to: (1) identify critical issues associated with CAVs that state and local transportation agencies and AASHTO will face, (2) conduct research to address those issues, and (3) conduct related technology transfer and information exchange activities [5]. To help the NCHRP 20-102 program facilitate research in these topic areas, a draft research roadmap was developed in 2015 as part of the NCHRP 20-24 project. The roadmap identified a list of projects under four general clusters – (a) Institutional and policy, (b) Infrastructure design and operations, (c) Planning, and (d) Modal applications [4]. Consequently, several research projects and task orders were initiated by NCHRP to cover the plethora of topics identified in the roadmap. Due to the fast-changing nature of this topic, NCHRP also identified recurring updates to the roadmap and related lists of research areas to keep up with the changing research needs.

1.1 Project Objective

The objective of this project, *NCHRP 20-102(19) - Update AASHTO's Connected and Automated Vehicle Research Roadmap*, is to update the 2015 roadmap and to identify priority research areas to focus on [6]. To support this objective, we are undertaking three distinct tasks, as shown in Figure 1.

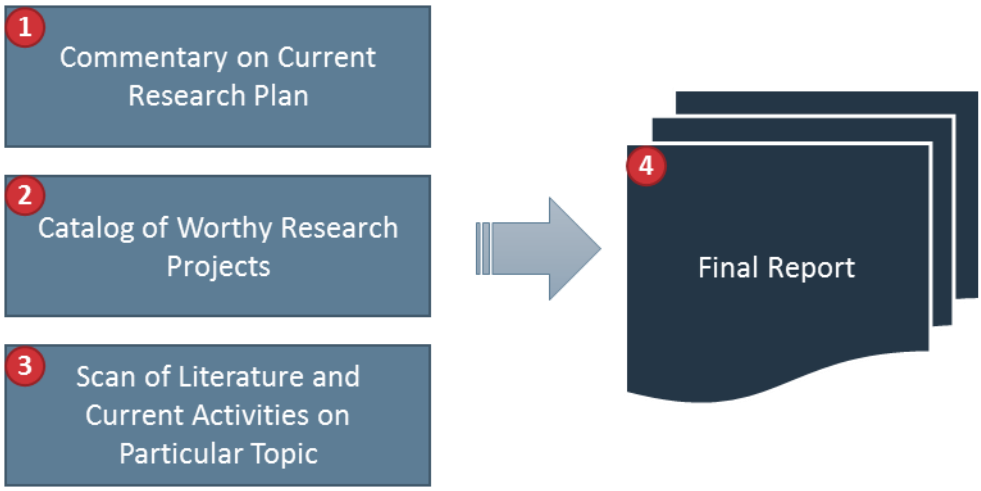

Figure 1. Tasks performed under NCHRP 20-102(19) Task Order

As a first step, the project team developed a commentary on the current research plan and the research completed to date. The commentary not only includes major findings from existing research but also an analysis of the gaps in research from the original vision and how the findings map to the current state-of-the-art. This analysis, along with inputs from industry and subject matter experts, fed into the development of a catalog of worthy research projects during the Task 2 of this project. The methodology the team used to develop this catalog (summarized in this report) is provided in Figure 2. The next step of the project is to conduct a scan of literature and current activities on selected topics and to develop associated white papers.

1.2 Report Overview

The focus of this report is to document our findings for Task 2. The report will be updated in 2019 to incorporate the state-of-the-art in CV/AV research and research needs identified then. Figure 2 provides a summary of our approach in developing the catalog of research projects.

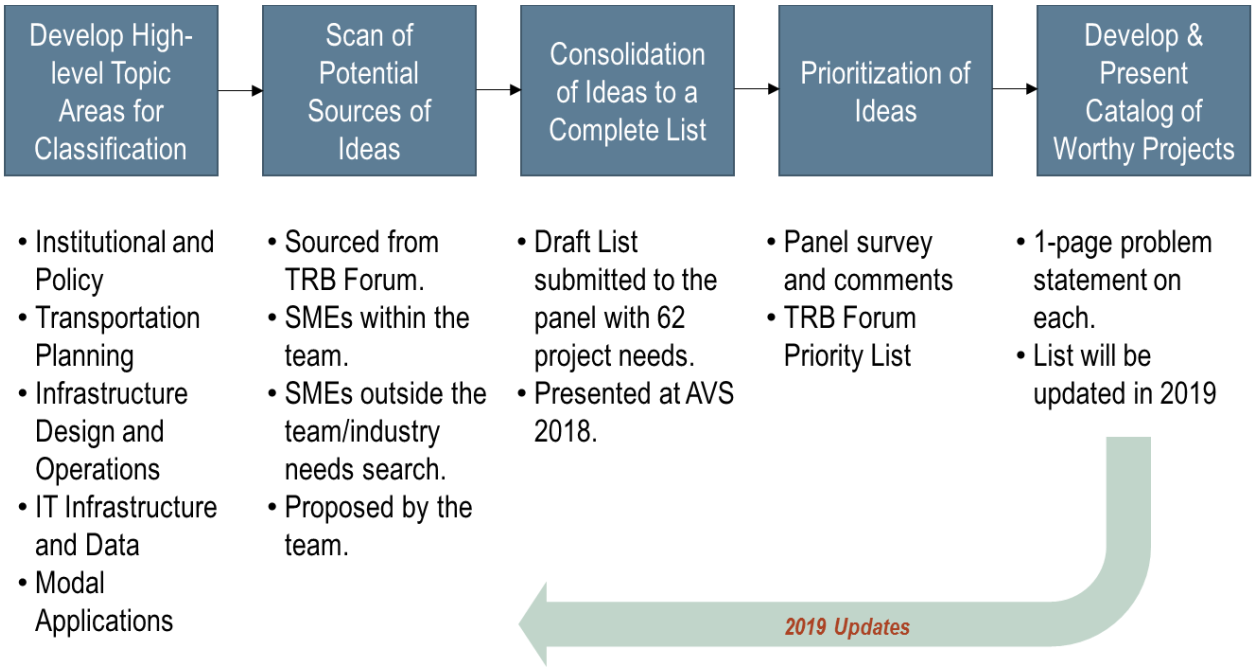

Figure 2. Task 2 Methodology

As shown in the figure, the team developed high-level areas for classification of topics. The major categories of topics included (a) Institutional and Policy, (b) Transportation Planning, (c) Infrastructure Design and Operations, (d) IT Infrastructure and Data, and (e) Modal Applications. The project team then conducted a scan of potential research needs, which were consolidated to a list of over 60 research topics presented in the next chapter. The topics were sourced from a parallel effort conducted by the TRB Forum for Preparing for AVs and Shared Mobility, subject matter experts both from within the team and external to the team, as well as new topics of interest proposed by the project team and other contractors who are part of the NCHRP 20-102 contract. In addition, topics were also sourced from the gaps analysis that were conducted as part of Task 1 of this project. The resulting list was presented to the NCHRP panel, and 11 projects were identified to be evolved into a research roadmap. These topics, along with a one-page summary identifying the background, research objectives, and intended outcomes, are also presented in this report.

This report is divided into five chapters:

1. **Introduction:** This chapter introduces the project and task objectives.
2. **Initial List of Research Topics:** This chapter lists the 60+ topics that were consolidated by the project team under the five categories of research in the CV/AV area.
3. **Prioritized Research Topics:** This chapter details our prioritization exercise and the selected topics to be included in the revised roadmap.

4. **Detailed Research Roadmap:** This chapter demonstrates one-page summaries for each of the selected topics.
5. **Next Steps:** This chapter discusses next steps for the project team using the findings from this report.

2. INITIAL LIST OF RESEARCH TOPICS

In this chapter, we summarize the initial list of research topics that the research team developed and cataloged. These research needs were derived from a variety of different sources, including conversations with external stakeholders, subject matter experts, analysis of gaps in CV/AV research, as well as from the TRB Forum on Preparing for Automated Vehicles and Shared Mobility. The research needs presented in this chapter were further prioritized based on inputs from internal and external stakeholders to help the project team develop an updated research roadmap.

The initial research topics presented in this chapter consists of over 60 different topics that fall under five major categories of research – (a) Institutional and Policy, (b) Transportation Planning, (c) Infrastructure Design and Operations, (d) IT Infrastructure and Data, and (e) Modal Applications. These are listed in the following sections.

2.1 Institutional and Policy Topics

The project team identified 22 research topics under this category. They are listed in Table 1.

Table 1. Topics under Institutional and Policy Category

No.	Topic	Description
1	Clarification of federal-state relationship in the Federal Automated Vehicle Policy 3.0; State-Local and Federal boundaries of responsibilities.	Revisiting state regulatory approaches and frameworks based on the new legislation that eventually passes Congress and the updated Federal Automated Vehicle Policy 3.0, to determine what the states need to do to serve their needs and interests, and to further clarify the federal-state relationship. This research may also include guidance for territories and protectorates which are governed indirectly by Federal regulations. This will be closely tied to the responsibilities of state-versus-federal, in terms of AV certification and testing. States are currently responsible for inspection and certification, whereas FMVSS uses self-certification of vehicle's safety systems. The research could also entail state-vs-local jurisdiction in AV-related policy making. (This topic should be revisited upon release of FAVP 3.0)
2	Guidance standards for CV/AV pilot testing	Develop guidelines for legislators and regulators regarding the requirements that they should impose on the organizations who want to test prototype CAV systems in their jurisdictions. Given the broad nature of testing various elements of ADSs and testing individual components versus strings of components, this may require ongoing enabling-technologies work for agencies to understand some ongoing testing methods and standards. Important to recognize different key use cases in these standards--for instance, freight/goods movement, shared mobility, and private vehicles--as these may have different needs (e.g., permits, insurance, data requirements, etc.). The research must be coordinated with other ongoing activity in the

No.	Topic	Description
		same domain by at least SAE, AAMVA, and the Uniform Law Commission.
3	Research alternative non-governmental mechanisms for vetting automated vehicle safety	Given that the national trend within U.S. DOT and Congress appears to be moving away from regulations to govern the safety of driving automation systems, it would be useful to explore alternative non-governmental mechanisms for vetting their safety, reviewing the "voluntary" safety assessments, and establishing criteria or grading systems so that the public has access to sufficient information to make informed decisions about which AV systems are likely to meet their expectations for safety.
4	Effective interactions between AVs and law enforcement and first responders	The law enforcement and first responder communities need to learn how they can interact safely with AVs when there is no driver in the vehicle, and it would be especially useful if there could be some coordination with the developers of the vehicle systems to provide common standards on the markings and the protocols for these interactions. As higher levels of vehicle automations are emerging, significant involvement from the law enforcement community is warranted. Research is necessary on the needs of first responders, considering vehicle identification issues that affect enforcement on the road, training for law-enforcement, first responders, and more.
5	Research focusing on guidance for CV/AV implication in public agencies and public policy	A research agenda that identifies the implications of CV/AV on public policy and provides recommendations for public agencies on developing policies to plan for and respond to CV/AV. For example, given the uncertainties associated with impacts of AVs on VMT, policies could be designed to encourage high occupancy modes or limit the use of zero occupant vehicles.
6	Development of public education and outreach materials regarding the perception of vehicle automation	Since consumers and elected officials still have a minimal level of understanding of driving automation systems and the media are inclined to focus on industry hype rather than reality, there is a need for authoritative public outreach material that can explain the full range of driving automation operational concepts and systems in easy to understand form. Such descriptions of automation concepts could also provide a useful foundation for surveys of public attitudes and for the development of regulations tailored to the needs of the different concepts. One of the first steps is to develop clear and consistent vocabulary for public consumption instead of SAE definitions that are more technical. Similar vocabulary must be developed from infrastructure perspective too.
7	Development of common system guidelines for	Since public confidence in the safety of automation systems is going to depend on open availability of authoritative and

No.	Topic	Description
	reporting vehicle testing and operations for public awareness	accurate information about the performance of those systems, common guidelines for reporting on the results of testing and of the public operational experience with the systems would be very useful.
8	Review of regulatory approaches and development of innovating approaches	What types of reforms could be implemented to enhance/expedite innovation? Are there legacy regulations/requirements that should be amended or ended altogether because of their obsolescence in an automated future?
9	Impacts of AVs and shared AVs on public transportation	Study impacts of AVs/SAVs on public transportation and how public transit might evolve in response to these changes. Also, how to encourage pooling in SAVs, reduce ZOVs; Managing transition from PT agencies during automation.
10	Harmonization of state regulations	Continue working on harmonizing the regulations for CVs and AVs, especially in the light of research and gaps identified as part of several previous 20-102 task orders. This work needs to be coordinated with the current work on this topic by AAMVA and the Uniform Law Commission, and there may also be activity with the National Council of State Legislatures, all of which arose after the original roadmap was created.
11	Lessons learned from other transportation technology roll outs	Reviewing lessons learned from CV pilots, AV proving grounds and demonstrations, and mobility-on-demand sandbox demonstrations. This would entail non-federal projects as well.
12	Workforce capability strategies for state and local agencies (including transit)	Agency workforces could be broadly affected by CAVs. For example, it could impact traffic engineers, planners, traffic incident management-(TIM) responders, emergency maintenance personnel, work-zone contractors, etc. Detailed study of implications on each of these categories would entail a significant effort. Hence the study must first define what kind of roles the infrastructure owners and operators will be playing in the future with CAV systems. The project should focus on those roles, and then an outcome would be identification of the training and capability development requirements. This research would also analyze strategies to prepare the future workforce for this disruptive change, including analysis of displaced and created jobs. The study would also address challenges in new network architectures and relationships with various IT departments within DOTs and state and local governments in general. The impacts would include all the various departments within an agency - procurement, public affairs, finance, etc - not just engineering, operations, and maintenance

No.	Topic	Description
13	Potential safety impacts of AVs	AVs are anticipated to interact with human-driven vehicles for the foreseeable future. Will there be any potential adverse impacts on safety due to this? This could be divided into phases - AV-non-AV interactions, AV-pedestrian interactions, AV-bicyclists interactions, etc. What will be the potential impacts on safety?
14	Determining how safe is safe enough	This should be a study of societal attitudes about AV safety and public expectations for AV safety, both as potential AV users and as other road users sharing the public road space with other people's AVs. This must be coordinated with some other research related to public attitudes about AVs involving Arizona State University and Missions Publiques in France.
15	Liability in a world of AVs	The insurance industry will see a disruptive change with the advent of AVs. This research will entail identifying the impacts of AVs on insurance and tort law. Auto insurance is regulated at the state level, and there are significant differences in the regulations in different states. Until now, none of those regulations have addressed the differences in insurance that will occur when part or all of the driving task is automated. A study is needed of the changes that may be required in insurance regulations to account for driving automation, when the driver may not be at fault, but the fault could be assigned to a vehicle system. What kinds of data would be needed to support clear allocation of responsibility for crashes? What are the implications for states that have no-fault auto insurance as well as fault-based systems?
16	Impacts of shared mobility during evacuations, disaster relief etc.	What are the impacts of shared mobility during evacuations, if vehicle ownership declines? This topic should include recommendations and best practices for public agencies (local, state, and federal EMAs) to provide evacuation services. Additionally, what are the impacts of shared AVs in disaster relief (e.g. natural disasters, terrorism).
17	Benefit-cost analysis of AV transit systems	This will require assessment of temporal scenarios for the deployment of CVs and AVs of different classes of vehicles. There is some past research done in this area, but this is a highly dynamic topic, and scenario projections might change every year.
18	Synergy within the transportation ecosystem	This research primarily deals with synergies that exist between different technologies and vehicles within the transportation ecosystem, such as convergence between connected and automated vehicles, AV deployment in a shared environment, urban/suburban/intercity/rural transportation infrastructure,

No.	Topic	Description
		different types of users, impacts of modal applications on each other, etc.
19	Evaluation of pilot deployments to determine contributions to various societal goals	Pilot deployments of AV, CV, and shared mobility are happening in several cities. As a consequence, most cities just evaluate them for mobility and/or safety performance measures. This research would expand the evaluation to include societal goals, including equity.
20	Framework for connected vehicle pilot and smart cities data analytics for policy guidance	CVs/AVs and smart cities produce a lot of data regarding travel behavior indicators. Capitalizing on these data, agencies can make policy decisions throughout their decision-making process. Developing a framework for this can help agencies in adopting these data-centric capabilities.
21	Alternative scenarios for synergy among automated vehicles, shared mobility, & alternative fuels (look at Dan Sperling's book)	This consists of developing scenarios for CV/AV/SMs, including (a) scenario planning with critical paths and use cases, (b) auto ownership scenarios and implications, (c) rate of deployment of mixed fleet and implications, (d) impacts on land use and density, (e) common sets of deployment tools for freight operations, (f) linkages between AVs, EVs, CVs, and SM, (g) models for MOD and MAAS, (h) impacts of airport landside operations, seaports and other intermodal facilities. [fully evolved future]
22	Certification of AV performance and safety	No technical standards have been defined yet to govern the performance and safety of AV systems, which makes it impossible for a developer or a third party to certify that a vehicle can satisfy a standard. Given that, research is needed to determine what aspects of the performance and/or safety of an AV system could be certified by the developer or a third party, based on technological, liability and political constraints, within the near future before formal standards have been defined. [role of states]

2.2 Transportation Planning

The project team identified 9 research topics under this category. They are listed in Table 2.

Table 2. Topics under Transportation Planning Category

No.	Topic	Description
1	Infrastructure/land use impacts of shared automated vehicles	Research on implementation of Shared Automated Vehicles (for both goods and people movement) and their impact on urban environment and infrastructure, economy and labor force, public transit, accessibility, etc. Research is needed on facilitating active/livable communities and assessing the impacts on the built environment. Consideration for land use in

No.	Topic	Description
		rural areas need to be included. How is the built environment re-purposed in an automated future to minimize economic blight (motels, drive-through, gas stations, repair shops, and other auto-oriented uses)?
2	Equity impacts of SAVs on communities	Where do the vehicles roam, where do they park, and where do they charge? How do we ensure low income communities aren't waiting areas for SAVs? How do we ensure equitable access for a variety of populations and geographies, etc.?
3	Research focusing on guidance for socio-economic impacts of transformational technologies	A research agenda that helps public agencies understand the potential impacts of transformational technologies on land use, the built environment, and planning. Metrics for socio-economic travel behavior (e.g., vehicle ownership, usage); land use (e.g., walking score, safety); employment and economic impacts (e.g., travel cost, employment indicators); infrastructure (e.g., efficiency); and environmental impacts can be used to monitor and assess the impacts of CV/AV. This research should have scope bounds.
4	Research focused on urban planning and infrastructure development	Research that informs land use planning and decision-making, such as understanding zoning and roadway infrastructure changes, may be needed as vehicle ownership patterns change (e.g., the impacts of CVs/AVs on sprawl and greenfield development). For example, parking pattern changes, repurposing parking lots, etc. This may be a longer-term issue, and could be revisited later, but could also impact long-range transportation plans.
5	Tools for predicting AV/CV impacts	Developing tools or a toolkit to predict the CV/AV impacts would serve as a common platform for agencies to justify investments. Some of this work is being done by FHWA under Saxton Labs.
6	Including consideration of AV systems in the regional planning process	This study should expand the current project that studies the impacts of CV/AVs on regional planning process to include mobility-on-demand and shared mobility. This could include Long-Range Transportation Planning methods, 4-step processes, etc.
7	Potential impacts of higher level automated vehicles and shared mobility on traveler behavior	The potential impacts of HAVs and shared mobility on VMT, system capacity, and behavior of other road users, with consideration of zero occupancy vehicles, need to be researched.
8	Implications for transportation planning and planning models	This would include (a) modeling the impacts of increased penetration of AVs and shared mobility, (b) revisiting traditional 4-step planning processes, (c) changing near-term or real-time planning processes, and (d) planning for rural areas.

No.	Topic	Description
9	Potential impacts of higher level automated vehicles and shared mobility on freight movement	The potential impacts of HAVs and shared mobility on freight movements.

2.3 Infrastructure Design and Operations

The project team identified 12 research topics under this category. They are listed in Table 3.

Table 3. Topics under Infrastructure Design and Operations Category

No.	Topic	Description
1	Infrastructure modifications to improve the operational domain of automated vehicles	Taking a deeper exploration of the ways in which roadway infrastructure can and should be modified to facilitate driving automation, beyond the scope of the initial NCHRP project that is exploring improvements to pavement markings. This should include I2V communication systems, signage, and civil infrastructure such as curbs and barriers to provide different levels of segregation between the CAVs and other road users. [build on CRCS]
2	Infrastructure analysis of automation systems and work zone interactions	Since work zones are one of the most challenging environments for driving automation systems, an in-depth study of the interactions between the automation systems and work zone procedures and physical implementations should be conducted to develop recommendations for best practices on both the infrastructure and in-vehicle sides. This may closely tie with the discussion on standard formatting of work zone information for automakers.
3	Safety implications in a mixed vehicle environment	This study will assess the safety implications of a long-term mixed driving environment with regular, semi-automated, and highly-automated vehicles sharing the roads. This may also include security implications. Given the breadth of the topic, a first step may be to summarize ongoing research in this area from US and abroad.
4	Traffic management strategies with consideration of AV	This study will analyze the impacts of CAVs on existing traffic management strategies and how those strategies can be enhanced to support mixed traffic. Traffic management strategies could range from signal control to advanced traffic control strategies such as Active Traffic Management.
5	Geometric design concepts for AV systems	This research would entail studying alternative design concepts for AV-only facilities, such as dedicated AV lanes. Previous research on dedicated lanes was limited to freeways. Expanding this to arterials could potentially have value to agencies.

No.	Topic	Description
6	Infrastructure enablers for connected and automated vehicles and shared mobility - near term and mid-term	What kind of infrastructure changes are needed to accommodate CAVs and shared mobility vehicles? This will include design changes of roadways, intersections, streets, and more, including dedicated lanes. In addition, consideration should be provided to infrastructure needs for V2I, impacts on public agencies' procurement policies, and impacts on existing standards and standards development process. Considerations must be also given to curb space and parking management.
7	Long-term infrastructure enablers for CAVs/SAVs.	Similar to the research above, but in long-term, assuming 100% AVs on most roads. Longer-term issues apply to physical infrastructure changes that are planned for a 50+ year lifecycle.
8	Impacts on infrastructure funding	With more AVs and EVs, the traditional revenue streams might need updates. This research would entail analysis of CAVs on traditional revenue streams, with consideration for continued funding support for legacy systems, assessment of risk and rewards for investment planning, and analysis of pricing levers to support policies and societal goals.
9	AVs impact on asset management practices	This research will consist of high-level analysis of impacts of AVs on traditional infrastructure asset management with respect to higher VMT/road usage, etc.
10	Implications for work zones	Work zones typically form a confusing scenario for human drivers, with lane-markings, gore areas, and more that are unclear. Researching how to better design work-zones would help rapid deployment of AVs. This cross-cutting research may entail development of standards in communication of work sone data (JPO initiative). [Combo w/ #2]
11	Dedicated truck lanes	This would continue the work begun in NCHRP 20-102(08) by looking at automated truck applications. It would explore the perceived benefits/disbenefits for the public, outreach and education. A key question is “Why should a DOT invest in these?”
12	Dedicated lanes for arterials and urban streets	Dedicated lanes for AV radial urban corridors. Most low-speed automated vehicles (LSAVs) are planned for the urban core.

2.4 IT Infrastructure and Data

The project team identified 11 research topics under this category. They are listed in Table 4.

Table 4. Topics under IT Infrastructure and Data Category

No.	Topic	Description
1	Recommendations for privacy and open data	Public and private partnerships to standardize data, share data, and protect sensitive data can be key to leverage the benefits

No.	Topic	Description
	standards with respect to AVs/CVs	of CVs/AVs on the transportation network and encourage innovation. OEMs and service providers typically track several important data points the origin and destination (e.g., the pickup and return location), travel time, and trip duration. Standardizing data sharing and protection sensitive data will be key to the progress of CV/AVs and shared mobility. As such, privacy and open data standards are critical to ensuring compatibility for a variety of uses and platforms.
2	Developing frameworks and best practices for managing data from emerging technologies	Establishing frameworks or guidelines for use of the data available through emerging technologies (CV/AVs, routing apps, transportation assisting apps, payment and scheduling apps, shared mobility platforms, etc.) to more efficiently manage the transportation network and the supply and demand. An integrated transportation management operation is possible now more than ever, given the increased amount of data available on where the consumer is, what his/her transportation needs are, what suppliers are available, what the road condition is, etc. Questions to address: 1) data standards (what are the standards to ensure interoperable data); 2) open data (to encourage public-private and private-private data sharing); 3) data protection (who owns the data, how is proprietary and user personally identifying data protected); 4) data ownership (what data must be shared with the public agency and for what purposes) ; 5) FOIA/public records/tort reform (what types of reforms are needed to protect both proprietary and personally identifying user data from release through public records and/or legal processes) ; 6) What consumer protections are needed for consumers (and companies) if data is improperly secured or released?
3	Minimum set of data sharing between public agencies and private deployers	What kind of data could realistically become available to public agencies (within strong real-world constraints of privacy, intellectual property, and the business models of the companies developing the new systems), and how those could be used to support improvements in transportation operations?
4	Data sharing between AVs and law enforcement, first responders	Law enforcement and first responders frequently interact with drivers of vehicles who are in a "situation" or who are required to pull-over. How do we enable data-sharing between the two parties? What are the advantages and considerations?
5	Minimum set of safety data needed for AV operations and crash-investigations	This research will include two parts. First, what data sharing (if any) will enable faster and safer AV deployment? Is it same as the BSM data? Second, what data is required to be provided by AVs for proper investigation of an AV crash? What data is required to remodel such a crash for investigative purposes?

No.	Topic	Description
		What data can be transmitted to first responders to enable proper response?
6	Getting the most out of "Big Data"	CV/AV/SM are expected to improve data use in the transportation industry. With that assumption, research needs to be undertaken to assess limitations and capabilities of future technologies in communication and to document best practices in data curation, sharing and management. At an agency level, research needs to be performed to support investment planning for IT systems, data and staffing, and the importance of using transportation data to support smart cities.
7	Models for exchange of data	Data sharing can greatly improve system benefits of AVs, CVs, and shared mobility. Research to support public sector use of private data, and vice-versa, is required. Additionally, research should also entail considerations to making data available for research and planning models, protocols for data sharing and management for evolving freight supply chains, and models for sharing of crash data.
8	Meeting cybersecurity and privacy challenges	With more data, cybersecurity and privacy challenges will be greater than ever before. Researching these challenges and documenting successful models can help agencies address them.
9	Framework for connected vehicle pilot and smart cities data analytics for policy guidance	CVs/AVs and smart cities produce a lot of data regarding travel behavior indicators. Capitalizing on these data, agencies can make policy decisions throughout their decision-making process. Developing a framework for this can help agencies in adopting these data-centric capabilities.
10	Data formatting standards for AVs	Development of AV systems are happening in a fast and non-coordinated fashion. Similar to the establishment of CV standards, development of data formatting standards is vital to mutual data exchange between AVs. Need to coordinate with SAE's standards development that is happening in parallel.
11	Data analytics mechanisms to improve infrastructure - AV integration	Research on the types of information infrastructure needed to support AV deployment, with consideration of the trade-offs between public and private sector roles in establishing and operating that infrastructure. Identify potential changes in the public and quasi-public transportation infrastructure. This may include increased installation of sensors and actuators on existing infrastructure to improve connectivity and the collection of big data, limited technology infrastructure on the roadways, and the appropriate use of artificial intelligence.

2.5 Modal Applications

The project team identified 13 research topics under this category. They are listed in Table 5.

Table 5. Topics under Modal Applications Category

No.	Topic	Description
1	Analysis on the impacts of advanced automated transit	This could include new modes of public transit that are automated, such as low-speed shuttles. Analysis on the impacts (societal, infrastructure, environment, economics, etc.) of Advanced Automated Transit. Other impacts such as:1) equity, 2) land use, 3) data access and privacy, and 4) safety and security? In this research, bounding the studies to one or two use-cases is vital.
2	State and local impacts of automated freight transportation systems	The implications of Automated Freight Transportation Systems (such as truck platooning) for state and local agencies and their long-term transportation planning. Other impacts include 1) equity, 2) land use, 3) data access and privacy, and 4) safety and security. [long haul, drayage, short haul, distribution, inspection, enforcement, permitting, screening]
3	CV/AV applications for maintenance fleets	CV/AVs have great potential in maintenance fleets, such as snow removal, work-zone dampeners, garbage trucks, postal vehicles, etc. Some of these may even be near-term owing to the controlled environments they operate in.
4	Benefit-cost analysis of AV transit systems	A dedicated study assessing the benefits and costs of automated transit systems, including low-speed automated vehicles (LSAVs), is important, as agencies are moving forward with investing in such pilot projects.
5	Critical paths to highly automated vehicles	This will require assessment of temporal scenarios for the deployment of CVs and AVs of different classes of vehicles. This research would also entail case studies regarding SAVs.
6	Impacts of shared mobility on transit	This would entail research on using shared mobility in solving first- and last-mile issues, importance of automated shared mobility, and models for integration of AVs and shared mobility with existing transit systems. It will also assess use of AVs to fill transit gaps, such as late-night transportation.
7	CAVs and shared mobility impacts on travelers with accessibility restrictions	This AV/CV/SM research will consist of assessing best practices in serving travelers with accessibility restrictions. This may entail use cases on current shared mobility work on equity and ease of access.
8	Preparing drivers and travelers for automated transit/freight vehicles	This will include driver training/DMV testing to prepare drivers and passengers for an automated future. A lot of the crashes aren't pure mechanical malfunctions but involve a failure in the interaction between the driver and the vehicle system. This could include training similar to pilots taking over failures in

No.	Topic	Description
		automated systems within seconds (MATL - Maintain Aircraft Control; Analyze the Situation; Take Proper Procedure; Land As Soon As Possible/Practical). Perhaps we need to train Level 3/4 drivers for MATP - Maintain Vehicle Control; Analyze the Situation; Take Proper Procedure; Park (or Pullover) as soon as possible/practical.
9	Consumer willingness to share "driverless" AV taxis with strangers	One of the main hopes for reducing traffic congestion and energy and environmental impacts through use of CAV technology is encouraging shared rides in AV taxi services. However, this depends on the willingness of consumers to share those rides with total strangers in a vehicle with no certified authority figure. Research is needed on the attitudes of a wide range of consumers toward this type of sharing and what countermeasures would be needed to provide them with a high enough level of confidence in their personal security (and the security of their unaccompanied children or senior parents) that they would be interested in using such services.
10	Organizational Implications of AVs on Transit Agencies	What organizational changes should transit agencies consider to prepare for automated transit?
11	Transit Operations Control Center Concept of Operations	Automated transit will cause profound changes in how transit agencies operate their fleets. This project will develop an initial concept of operations for transit operations centers.
12	Design for Automated Transit Routes	This project would develop specific design guidance for automated transit routes and facilities.

3. PRIORITIZED RESEARCH TOPICS

Once the research catalog was developed, the NCHRP panel conducted a prioritization exercise to identify top research needs for problem statement development.

No.	Potential Research Topics	Benefits							
		Improve Safety	Increase Efficiency	Cost Saving	Ease Congestion	Accessibility	Economic Dev.	Increase Security	Public Awareness
1	Workforce capability strategies for state and local agencies						✓		✓
2	Alternative scenarios for synergy among automated vehicles, shared mobility, and alternative fuels						✓		
3	Infrastructure/land use Impacts of shared automated vehicles	✓	✓	✓	✓	✓	✓		
4	Potential impacts of higher level automated vehicles and shared mobility on traveler behavior.	✓	✓		✓				
5	Infrastructure modifications to improve the operational domain of automated vehicles	✓	✓	✓	✓	✓			
6	Infrastructure enablers for connected and automated vehicles and shared mobility - near term and mid-term	✓	✓						
7	Implications for work zones	✓	✓						
8	Analysis on the impacts of advanced automated transit		✓	✓		✓			
9	State and local impacts of automated freight transportation systems		✓		✓		✓		
10	CV/AV applications for maintenance fleets		✓		✓		✓		
11	CAVs and shared mobility impacts on travelers with accessibility restrictions		✓			✓	✓		

4. DETAILED RESEARCH ROADMAP

In this chapter, the project team presents problem statements for the eleven research topics selected by the NCHRP 20-102 panel. The final selection of which ones to fund will be made in Fall 2018.

1. Workforce capability strategies for state and local agencies
Background: The transportation industry is rapidly expanding, and new technologies are creating connective networks that are merging the physical and digital worlds of transportation. The pace at which these technologies are evolving is creating workforce challenges for the transportation industry as new skills are quickly becoming essential to deploy, operate, and maintain these technologies. The transportation industry requires new and modified training opportunities to effectively acquire these advanced skillsets.
Research Objectives: New technologies, such as connected vehicles, connected infrastructure, smart cities, and automated vehicles, are changing the landscape of the physical and digital worlds of transportation and redefining necessary skillsets to achieve successful deployment. These changing workforce needs for state and local agencies must be researched. Key research objectives include: • Understanding the array of training opportunities/resources currently available to state and local agencies • Understanding the areas of incoming technologies that state and local agency personnel feel most comfortable/uncomfortable with • Determining the new/anticipated skillsets that will be required of state and local agency personnel and which will require the most amount of training • Determining gaps between currently available training resources and necessary new skillsets • Understanding the most impactful method of delivery/resource format for the needed new training materials • **Understanding how to best evaluate the effectiveness, employee satisfaction, and return on investment of suggested workforce development strategies**
Intended Outcomes: Outputs of this research will inform state and local agencies on how to best prepare their personnel for successful connected automated vehicle (CAV) deployments. Research results will determine the current training landscape, anticipated skillsets/training needs, training gaps, and strategies for successful training delivery/evaluation. Enhancing the focus on newfound/anticipated training needs and achievement strategies will promote a universal understanding of CAV concepts throughout state and local agencies while effectively guiding personnel to successful CAV deployments.

2. Alternative scenarios for synergy among automated vehicles, shared mobility, and alternative fuels
Background: Transportation is on the verge of rapid transformation. The convergence of mobility services, shared modes, electrification, and automation will undoubtedly transform how people and goods move, how cities are designed, and transportation infrastructure required to meet the needs of this transformation. The impacts of emerging technologies on auto ownership, parking, and travel behavior remain to be seen. However, as these technologies come online, policymakers will need to understand triggers, tipping points, and timelines that define important shifts in how the transportation system is operating due to changes in technology and society.
Research Objectives: This research consists of developing scenarios for Connected Vehicles (CVs)/Automated Vehicles (AVs)/Shared Mobility (SM) including: (a) scenario planning with critical paths and use cases, (b) auto ownership scenarios and implications, (c) rate of deployment of mixed fleet and implications, (d) impacts on land use and density, (e) a common set of deployment tools for freight operations, (f) linkages between AVs, EVs, CVs, and SM, (g) models for Mobility on Demand (MOD) and Mobility as a Service (MAAS), and (h) impacts of airport landside operations, seaports, and other intermodal facilities. The project will focus on the transition leading up to a fully evolved future.
Intended Outcomes: AVs, shared mobility, and alternative fuels can have a notable impact on mode choice, vehicle miles traveled (VMT), congestion, and emissions. Modeling that does not incorporate these areas may not produce robust results that planners and public agencies can rely upon. The intended outcomes of this research include: • A summary of the relevant transportation planning and modeling literature including a focus on how modeling can be adapted in response to AVs, shared mobility, and alternative fuel vehicles. • Scenarios that identify and forecast changes in auto ownership, rate of deployment of a mixed fleet, changes in land use and the built environment, etc. during the transition and leading up to a fully evolved future; and • **Recommendations for policymakers on how to manage the transition to an automated, shared, zero carbon future.**

3. Infrastructure/land use impacts of shared automated vehicles
Background: The convergence of automated vehicles and shared mobility creates both stresses and opportunities affecting land use, infrastructure, and that potentially promoting or hampering livable, active communities that are attractive to populations living there. Decisions made will help determine the best outcomes, and the long lead time of some items such as land use policies lends added criticality to take actions in partly uncertain environments. Governments, particularly at the state, regional, and local levels, must take an active role in setting laws and regulations that will create outcomes consistent with their goals and properly harnessing the direct and indirect implications of the shared AV use. The dynamic of shared AVs in affecting policy decisions such as in land use may differ in urban, exurban, and truly rural areas. For example, rural areas generally have higher proportions of older, lower income, and disabled people. Exurban areas may be characterized by urban sprawl and therefore have street network and traffic density considerations different from other areas. Each of these environments must be uniquely considered in a broad assessment of the issue. An important specific example of the changes is that more urban environments can be expected to require much less parking of all types (street curb, parking lot, and parking structures). Such a change has quite wide-ranging effects. Municipalities will likely be affected as parking revenues decline. Public revenue sources and uses are also an important consideration. Current municipal, regional, and state revenue sources are expected to decline in a shared AV environment, with reduced gas use, vehicle registration fees, and parking fees (but there are thoughts on replacing these sources). Urban areas around the world are beginning to experiment with novel approaches for use of the curb, and this might increase with the advent of shared AVs. New uses are possible, as are management schemes such as time-phasing the usage designated for curb lanes. Shared use AVs may be allowed on particular lanes or roads, and non-shared use vehicles could be restricted on certain lanes or roads.
Research Objectives: The research project has the primary objective of identifying and evaluating public sector policies that will help ensure the safe and successful integration of shared AV into current built environments. These policies, rendered as laws or regulations, should be harmonious with the current status of the federal regulatory approach towards AVs. The evaluation should discuss the conditions under which policies may be appropriate or desirable. Policies should span across elements such as parking and other land usage, along with considerations in management (e.g., in lane curb repurposing), economics, social issues, environmental sustainability, and safety. The evaluation should also include considerations for timing – when policy elements need to be in place, perhaps under different assumptions of adoption rates. The research should define the impacts of shared use AVs within a broader context that includes other initiatives that help shape, promote, or are at odds with shared use AV infrastructure impacts (including but not limited to electric vehicle developments and smart community initiatives).
Intended Outcomes: Policy suggestions, algorithms, or tools for state, regional, and local governments to successfully adapt to a shared AV environment. Guidance should be appropriate for urban, exurban, and rural areas, and distinguished as such. For governments to develop a better understanding of the conditions under which planning and asset management decisions should be made and the positive and negative impacts of a suite of possible decisions.

4. Potential impacts of highly automated vehicles and shared mobility on traveler behavior

Background: In recent years, economic, environmental, and social forces have quickly given rise to shared and on-demand mobility, a collective of entrepreneurs and consumers leveraging technology to share transportation resources, save money, and generate capital. Ridesourcing/transportation network company (TNC) services, such as Lyft and Uber, and peer-to-peer carsharing services, such as Getaround and Turo, have become part of a sociodemographic trend that has pushed shared on-demand mobility from the fringe into the mainstream. A number of social, environmental, and behavioral impacts have been attributed to shared mobility, and an increasing body of empirical evidence supports many of these relationships. The various effects can be grouped into four categories: (1) travel behavior, (2) environmental, (3) land use, and (4) social. These impacts can include sold vehicles or delayed or foregone vehicle purchases; increased use of some alternative transportation modes (e.g., walking, biking); changes in vehicle miles/kilometers traveled (VMT/VKT); increased access and mobility; and reduced fuel consumption and greenhouse gas emissions (particularly when fleets are electrified); and greater environmental awareness. However, the impacts of automated vehicles (AVs) and shared AVs (SAVs) are uncertain. One possible outcome is that existing roadway capacity may increase due to more efficient operations associated with automation (e.g., closer vehicle spacing, etc.). Conversely, there is a possibility for widespread AV and SAV adoption that could induce VMT by making automobile trips more convenient and affordable with fewer hassles than personal driving, such as parking. This could potentially negatively impact the nation's roadway infrastructure through increased VMT and vehicle use. As such, more research is needed to understand the impacts of highly AVs (HAVs) and SAVs on travel behavior.

Research Objectives: The potential impacts of HAVs and shared mobility on VMT and system capacity, as well as the behavior of other road users, particularly in light of the potential for zero occupancy vehicles, needs to be researched. Key objectives of this research include:

- Understanding the impact of HAVs and SAVs on private vehicle ownership and use in an automated future;
- Understanding the relationship and interaction of HAVs and SAVs on public transportation;
- Understanding the impacts of HAVs and SAVs on individual modal choice and willingness to use active transportation, public transportation, and other modes; and
- Understanding the VMT, congestion, air emissions (greenhouse gas [GHG] emissions and criteria pollutants) of SAVs and HAVs under a variety potential deployment scenarios, such as:
    - The travel behavior and environmental impacts of HAVs and SAVs on jobs and housing location decisions (i.e., will HAVs/SAVs encourage denser urban cores, suburban/exurban growth, or a combination of both, and under what circumstances?);
    - The travel behavior and environmental impacts of HAVs and SAVs based on business model deployment (i.e., business-to-consumer, peer-to-peer, or mixed fleets); and
    - The travel behavior and environmental impacts of HAVs and SAVs based on a variety of pricing and pooling scenarios (i.e., will zero occupant vehicles be permissible and, if so, under what circumstances?).

Intended Outcomes: Outputs from this research will inform policymakers at all level of government on the potential travel behavior impacts of HAVs and SAVs. The results of this research will help to inform proactive policy development to encourage positive HAV/SAV adoption outcomes, such as reduced congestion and air emissions (GHGs and criteria pollutants). Additionally, the results of this research will enhance understanding of the potential societal adoption and barriers associated with

SAV use and the willingness to sell or forego the purchase of a personal AV. Finally, this research will help the public sector understand the potential impacts of HAVs and SAVs on mode choice and the willingness of users to use active and public transportation in an automated future.

5. Infrastructure modifications to improve the operational domain of automated vehicles
Background: AV deployments will be limited to operational domains (OD) where vehicles can readily demonstrate safe operation. Limitations in ODs may stem from factors that challenge an automated vehicle's ability to accurately perceive the surrounding environment and effectively make decisions, such as adverse weather and degraded lane markings. City and state agencies may wish to extend the ODs to improve benefits, such as to improve economic opportunities and accessibility, connect strategic locations, and simply be an attractive place for AV testing and deployment. While agencies may not be able to control some of these OD limitations, they can take steps to modify infrastructure to improve the OD. Infrastructure modifications may include infrastructure to vehicle (I2V) communication systems, signage, and civil infrastructure such as curbs and barriers to provide different levels of segregation between the CAVs and other road users. Uniform and well maintained traffic control devices, such as lane markings and traffic signs, may improve the extent of AV ODs. AV functionality depends on perception algorithms to accurately detect and respond to infrastructure based on sensor information. Just as humans learn to drive through experience, many perception algorithms use machine learning that is trained to detect and classify objects and events based on past experience. Atypical conditions are more challenging for perception systems. Segregation can create a less complex environment by eliminating mixed road users that can be unpredictable or can even take advantage of an AV's conservative behavior. Infrastructure owners and operators want to understand how the OD of near term deployments may benefit from infrastructure modifications.
Research Objectives: This research will review and identify potential infrastructure modifications that could improve the OD of AVs. The analysis will: • investigate aspects of technology and operation that influence OD, such as vehicle connectivity, dedicated lanes, AV sensors, perception algorithms, operating speeds, and pickup/drop-off locations; • review lessons learned from AV testing and deployment activities; • identify and characterize aspects of physical and digital infrastructure elements that may limit OD, such as V2I, curbs, barriers, reflectivity, geometry, and quality of data; and • develop implementation guidance for infrastructure modifications, including potential improvements to OD, costs, and impacts to other road users.
Intended Outcomes: This research will provide state and local transportation agencies with guidance on how to modify infrastructure to improve the OD of AVs. The assessment will provide insights based on AV technology and operations. It will provide a catalogue of potential infrastructure modifications, and describe how these modifications will impact ODs. Key considerations for prioritizing potential modifications will be provided to infrastructure owners and operators to enable decision making and investments.

6. Infrastructure enablers for connected and automated vehicles and shared mobility - near term and mid-term

Background: Connected and automated vehicle (CAV) technologies are quickly advancing, and as a result there is a growing need for roadways and infrastructure, which were traditionally designed with human drivers in mind, to begin to consider the impacts of CAVs. In order to achieve a smoother transition to CAV transportation, state and local agencies must understand how and when traditional highway and street infrastructure may be affected and the impacts this could have on design, operations, maintenance, and policy.

Research Objectives: Existing NCHRP research is already exploring early impacts of potential design changes for roadways, intersections, streets, etc., including dedicated lanes. While an update of that research will undoubtedly be necessary (given how quickly technology is evolving), additional consideration should also be provided to impacts on public agency procurement policies, legislative/regulatory actions, and workforce needs and changes. In dense urban areas, consideration might also be given to curb space and parking management.

Key topics for exploration include:

- Design Standards and Guidelines - given the nature of lateral and longitudinal control of CAVs, what impact will this have on design standards that relied on human variability?
- Digital Infrastructure/Connectivity - CAVs will interact with physical and digital infrastructure in ways that impact their standards and practices. How will that create different network architectures and the need for new business models?
- Variable Roadway Features - features such as reversible lanes, dynamic speed limits, work zones, and dynamic shoulder use are designed for human perception. What types of changes might be needed, and are there alternative methods/technologies that need to be considered?
- Urban Design - in dense urban areas, what changes in curb space might be necessary to accommodate alternative pick-up/drop-off scenarios. What impacts (if any) to parking or vehicle storage might be anticipated?
- Roadway Markings – as more vehicles are equipped with next generation automated driving system (ADS) technology, what impact will this have on maintaining roadway markings and signage in a visible/retroreflective way, and supplementing these by newer technologies?
- Procurement and Regulation – CAV and transportation technology might require a policy-framework that is nimble enough to adapt to fast-changing needs, functional requirements, and product availability.

Intended Outcomes: Outputs of this research will update and expand the guidance for state and local transportation agencies in evaluating and—if necessary—adapting their standards, practices, and institutional frameworks for roadway and infrastructure, urban design, and related maintenance and operations to reflect the deployment of connected and automated vehicle technologies.

7. Implications for work zones
Background: Work zones pose challenges to the deployment of automated vehicles (AVs) due to the temporary and non-uniform nature of the infrastructure and traffic control devices. AVs perform best in structured environments with uniform rules and procedures. Furthermore, many AVs are being deployed with the aid of high-definition digital maps that improve perception and navigation by helping the vehicle anticipate roadway features. Work zones often use temporary lane markings, road edges, lane shifts, humans directing traffic, and other atypical traffic control devices that create challenging situations for AVs to perceive and navigate effectively. Many state, regional, and local agencies maintain work zone activity data. However, it can be difficult and costly for third parties, such as original equipment manufacturers and navigation applications, to access and use these data across jurisdictional boundaries because of a lack of common data standards and convening mechanisms. State and local transportation agencies may improve the safety and operational domain of AVs through improvements to work zones. Guidance is needed on the costs, benefits, challenges, and potential solutions for work zones, as well as implementation guidance.
Research Objectives: This research will assess potential challenges and solutions for AV implications on work zones. The analysis will: • Identify physical or digital aspects of work zones that challenge or improve AV operations, including non-uniformity of traffic control devices, temporary infrastructure, connectivity and data • Survey current work zone practices across a range of work zone configurations and geographic locations that relate to AV operations • Identify work zone enhancements that may improve AV operations, and assess both costs and benefits and also potential barriers or enablers to widespread adoption (e.g., standards) • Provide recommendations and guidance on implementation of work zone enhancements, including roles of key stakeholders (i.e., transportation agencies and contractors)
Intended Outcomes: Policy suggestions, data exchanges, or tool, for state, regional, and local governments to successfully improve work zones for AVs. Guidance should be appropriate for a range of work zone configurations and geographic locations. For governments to develop a better understanding of the costs and benefits of work zone enhancements. To provide a roadmap that identifies potential pathways and barriers to adoption of attractive solutions.

8. Analysis on the impacts of advanced automated transit
Background: Transit is changing rapidly as advanced technologies enable new or augmented services. These services have the potential to dramatically change people's travel experience and behavior. Automation has the potential to not only improve transit safety, but to reduce transportation costs, enable new business models, and improve accessibility. These new technologies include new options for transit, such as low-speed shuttles, that may be one of the earliest commercial on-road deployments of automated driving systems (ADS), defined as SAE Levels 3-5 automation. Shared mobility is impacting transit, and transit agencies need to get ahead of the even deeper disruptions ahead. Public policy and investment decisions for advanced automated transit will consider societal, infrastructure, environmental, and economic dimensions of deployments. The impacts of advanced automated transit remain unclear, and guidance is needed to help plan for and deploy these technologies. Policymakers will need to understand factors and metrics, assessment models, tipping points, and timelines that describe important impacts on society and transportation systems for years to come.
Research Objectives: This project will study advanced automated transit systems and assess their impacts. The project will survey technical solutions and readiness, business models, and planned or in progress deployments. The project will develop an impacts assessment framework. The analysis should focus primarily on the societal, infrastructure, environment, and economics impacts of advanced automated transit, and secondarily on other impacts such as equity, land use, data access and privacy, and safety and security. In this research, bounding the studies to one or two use cases is vital. The project will provide lessons learned from recent pilot programs and potential models for longer term deployments.
Intended Outcomes: The study will provide guidance for state and local transit agencies and partners to aid in planning, designing, procuring, and evaluating deployments. Automated transit will impact social, environmental, and behavioral factors. At the same time, shared mobility is disrupting transit and will influence impacts of advanced automated transit. Impact assessment models and guidance that incorporates these considerations may be more likely to produce desired results, or avoid unintended consequences, that planners and public agencies are seeking. The intended outcomes of this research include: • A summary of the relevant transportation planning, modeling, and deployment literature including a focus on how to model impacts of automated transit • Focused analysis on one or two advanced automated transit use cases that describes how impacts can be evaluated and influenced through planning, partnerships, concept of operations, business models, procurement, and deployment phases • Development of an impact assessment framework with societal, infrastructure, environment, economics, and other dimensions • Recommendations for policymakers on how to manage the transition to an automated transit future.

9. State and local impacts of automated freight transportation systems
Background: The automation of freight transportation systems is proceeding along multiple fronts and at a pace quite rapid by this sector's historical pace of change. Private capital is flowing into technologies and companies in this space at levels that are also unusual in the sector. Freight system automation occurs in several environments and throughout the SAE spectrum of automation levels. Truck platooning concepts are focused on corridors that emphasize interstates, but that also have application on major urban freeways. The relative ease of automating limited-access highways relative to urban areas is enticing new operating concepts to be thought about in which distribution centers and similar transfer points are increasingly located adjacent to highway access points, anticipating a future environment in which manned trucks are driven to the access point, followed by a highly-automated line haul run across the highway network. Within urban cores, the sector is enjoying a period of robust experimentation in last-mile automated freight delivery options, with localities struggling to keep up with legal, regulatory, land use and other issues within their jurisdictions. Marine and rail port environments present a different operating environment for the introduction of the same basic family of automation technologies. In 2016, NCHRP project 20-102(03) identified a set of research initiatives needed to advance automated (and connected) freight systems. The recommendations may be a starting point for updated research; they include the areas of planning, regulation, policy, application-level research, technical standards development, and stakeholder engagement. Topics such as physical and cyber security and privacy are included and important to consider.
Research Objectives: Research should identify the range of automated freight transportation systems that are under development or consideration, and assess likelihoods, timing, and expected penetrations of deployment. Within this range, the research should offer governments at the state and local level with an enumeration of the issues that impact them and insight on how to address. The research should also guide state and local governments to act in a way complementary to and in anticipation of the applicable federal guidance in effect at the time of this study (such as defined in the U.S. DOT's Federal Automated Vehicle Policy).
Intended Outcomes: Outcomes of this research should minimally include guidance and suggested best practices with regards to state and local decision making to provide a proper environment to evaluate and introduce automated freight transportation systems, covering all relevant functional areas of a state or local government's jurisdiction. Direction should also be determined for continued technical research on gaps that organizations such as the U.S. DOT, AASHTO, and TRB should consider to further define the need and help the local governments to succeed.

10. CV/AV applications for government truck fleets
Background: Governments at the state and local levels operate commercial truck fleets to serve a variety of functions, and a variety of CV/AV application areas are common to and even unique to this domain. Road maintenance fleets are key among these, and others include snow removal, garbage removal, and even postal fleets. Both light duty and heavy duty trucks are used, spanning a gamut of the FHWA gross vehicle weight rating classifications. There are numerous use cases emerging involving these fleets, manifesting today as research efforts, prototypes, test cases, and early deployments. The controlled environments that many of these fleets operate in make them attractive targets for early deployment. These deployments hold the promise of improving operational performance in a number of ways, including providing data to fleet operators, providing probe-based data collected in a consistent manner for various business functions, improving the quality and timeliness of decision making, and improving performance measurements. Use cases run a gamut from V2V connected vehicle, V2I connected vehicle, automated vehicle, and connected automated vehicle. Maintenance vehicle V2I use cases can be attractive for early deployment because the infrastructure owner and the vehicle owner often overlap (specifically, a public agency owns both). Applications, including work zone warnings, are under consideration. These use cases can be more easily constrained, and fleet populations are under common control. Road weather applications are another family of opportunity, spanning the V2V and V2I space; more recently AV applications have been considered.
Research Objectives: Reporting done under this research project should review experiences to date in developing, testing, and implementing CV/AV applications for government-operated commercial truck fleets, including relevant international experiences. It should present any emerging best practices and define outstanding research needs. It should develop strategies for various fleet owners to understand how and when applications and groups of applications should be pursued, including characteristics of operating environments that would be most fruitful.
Intended Outcomes: The research should minimally include: • A survey of current and anticipated use cases in the application of CV/AV applications for commercial fleets operated by government authorities • Recommended next steps needed to help qualify and promote promising CV/AV applications, including additional research activity Recommendations around transitional topics for government authorities, such as addressing labor and union issues, fleet turnover, maintenance needs, etc.

11. CAVs and shared mobility impacts on travelers with accessibility restrictions

Background: Shared and automated mobility can create opportunities to enhance access and equity by providing increased mobility options (e.g., fares, routes), increased travel speed and reliability, critical first- and last-mile connectivity, and expanded coverage to historically underserved users or communities. However, shared and automated mobility can also result in disparate outcomes, if individuals or households with special needs are unable to access shared or automated mobility options. Understanding the equity impacts of a shared and automated transportation network can be difficult to assess because there are several types of equity issues impacting the transportation network. With the proliferation of private mobility services often requiring a smartphone, mobile internet access, and/or credit and debit cards, these services can raise a wide array of potential environmental justice and social equity issues including digital poverty, unbanked and underbanked users, service access to low-density and rural areas, affordability, and access for older adults and people with disabilities. Beyond these, there are concerns about vehicle and system designs considering persons with disabilities, which may stem from factors such as lack of awareness of user needs, lack of universal design standards and widespread adoption of these standards, or lack of funding to incentivize these features. While environmental justice, social equity, and accessible design have been important considerations for the transportation sector, there is limited understanding, statutory and regulatory guidance, or legal precedents on how these laws may impact private transportation modes, such as shared automated vehicle (SAV) service providers.

Research Objectives: This Automated Vehicle (AV)/Connected Vehicle (CV)/Shared Mobility (SM) research will consist of assessing best practices in serving travelers with accessibility restrictions. This may entail use cases focused on current shared mobility work on equity and ease of access.

- Understanding the impacts of AV/CV/SM on access and mobility for a variety of special populations and demographic segments (e.g., children, prenatal mothers, persons with disabilities, veterans, etc.);
- Understanding the impacts of AV/CV/SM on access and mobility for users are unable to access mobility on demand (MOD) because of the lack of mobile internet access or understanding of how to use these services (e.g., older adults, rural residents, low income);
- Understanding how AV/CV/SM can be used to enhance access and mobility for people with disabilities, such as:
    - Providing ambulatory and non-ambulatory access and mobility to people with disabilities;
    - Methods for handling payment for services among providers, including subsidies;
    - Identifying the types of equipment standards and worker training are necessary to provide people with disabilities;
    - Identifying transformative solutions, applications, and systems that can be employed to expand services to people with disabilities and ensure equivalent service; and
    - Understanding the types of policies that need to be in place to ensure equivalent access/level of service for vulnerable populations and users with special needs (e.g., low-income communities, minority neighborhoods, people with disabilities, etc.).

Intended Outcomes: The outcome of this research will provide policymakers with actionable research and recommendations that can be employed to enhance AV/CV/SM access to a variety of populations, including but not limited to people with disabilities, low-income and digitally impoverished households, and older adults. The results of this research will help inform proactive policy development to encourage equitable access for all transportation users in a shared and automated future.

5. NEXT STEPS

In this task, the project team developed a prioritized research roadmap for the NCHRP 20-102 program to further the connected and automated vehicle research to support state and local transportation agencies. The roadmap is reflective of state-of-the-art industry needs gathered from different sources. The next step of this project entails developing three white papers on topics of interest to the NCHRP panel. The project team recommends the following three topics as they represent immediate research needs for the transportation community.

Topic 1 – Educating the public on automated vehicles and their implications, myths, and facts.

Topic 2 – Future of Transportation – Convergence of connected and automated shared electric (CASE) vehicles in a multi-modal world.

Topic 3 – Implications of AV/CV cybersecurity for state and local agencies.

These topic suggestions are based both on themes that were highlighted in plenary and breakout sessions of the 2018 Automated Vehicle Symposium and also on perceived gaps in existing research activities. While the 11 topics proposed in Section 4 can be easily summarized in one page, each of these three topics would benefit from a review of literature and industry trends in order to inform the NCHRP community and formulate the research needs.

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