Investigating Key Automated-Vehicle Human Factors Safety Issues Related to Infrastructure: Summary of Stakeholder Workshop

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FOREWORD

In recent years, there has been rapid growth and development in motor vehicle driving automation systems aimed at enhancing the safety of drivers. As the current vehicle fleet becomes increasingly more automated, vehicles with engaged driving automation features, referred to in this document as automated vehicles (AVs), must be able to interact with roadway infrastructure. The Federal Highway Administration is funding a project that investigates the safe operation of AVs in relation to infrastructure. The project focuses on Level 2 and Level 3 of SAE's driving automation taxonomy. As part of the project, the research team held an in-person workshop to engage stakeholders and develop a list of prioritized research topics, which will guide studies of this project, in the areas of human factors and SAE Level 2 and Level 3 driving automation as a function of roadway infrastructure. This report details the outcomes of the stakeholder workshop.

This report may be of interest to transportation practitioners, those conducting transportation safety and/or human factors research, industry, and those working to improve transportation safety.

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16. Abstract
This project, Investigating Key Automated-Vehicle Human Factors Safety Issues Related to Infrastructure, has three key objectives: (1) develop an increased understanding of AV human factors and safety issues related to roadway infrastructure through analysis and experimentation, (2) produce data and results to aid the design of infrastructure elements that better support the operation of AVs, and (3) produce information to support operational standards development and potential performance-requirements activities. The research team conducted an in-person workshop with 18 stakeholders to develop a list of prioritized research topics in the areas of human factors and SAE Level 2 and Level 3 driving automation as a function of roadway infrastructure. The participants agreed on a consolidated list and then voted on three topics they thought were most important to address through further research. The results are a prioritized list that will be considered for further study by the research team. The prioritized list will guide the design of a driving simulator and test track or on-road experiments that explore driver safety as a function of AVs and infrastructure.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1,000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	2.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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LIST OF ABBREVIATIONS

AV	automated vehicle
DOT	department of transportation
FHWA	Federal Highway Administration
MUTCD	*Manual on Uniform Traffic Control Devices*
NCHRP	National Cooperative Highway Research Program
ODD	operational design domain
OEM	original equipment manufacturer
TCD	traffic-control device
TRB	Transportation Research Board
TTI	Texas A&M Transportation Institute
VRU	vulnerable road user
VSL	variable speed limit

CHAPTER 1. INTRODUCTION

The focus of this project, Investigating Key Automated-Vehicle Human Factors Safety Issues Related to Infrastructure, is to identify key human factors safety issues regarding the safe operation of vehicles with engaged motor vehicle driving automation features, referred to in this document as automated vehicles (AVs), as a function of roadway infrastructure. The project focuses on Level 2 and Level 3 in SAE's driving automation taxonomy, referred to in this document as SAE Level 2 and Level 3 AVs. The project includes three high-level tasks: literature review, gap analysis, workshop, and research priorities; develop work plan; and execute work plan. Key objectives of the project include the following:

- Develop an increased understanding of AV human factors safety issues related to roadway infrastructure through analysis and experimentation.
- Produce data and results to aid the design of infrastructure elements that better support the operation of AVs.
- Produce information to support operational standards development and potential performance-requirement activities.

As part of task 1 of this project, the research team completed a literature review and gap analysis identifying high-level safety issues related to human factors and AVs as a function of infrastructure. The research team then conducted a workshop to bring together stakeholders, including experts in AVs, infrastructure, human factors, and related topics, to develop a list of prioritized research topics for consideration in developing driving simulator and test track or on-road studies as part of the project.

CHAPTER 2. AV INFRASTRUCTURE WORKSHOP

WORKSHOP PREPARATION AND STAKEHOLDER IDENTIFICATION

The research team prepared for the workshop by creating a general meeting structure and identifying areas of expertise that could provide diverse and relevant perspectives. Invitees were identified through summaries of responses to previous related workshops and the research team's awareness of specific organizations and professional network. The research team attempted to balance representation across areas of expertise and sectors, including Federal and State representatives.

Two months before the workshop, the research team emailed an invitation to approximately 65 invitees representing the following areas or organizations:

- State departments of transportation (DOTs) and departments of public safety.
- The Federal Highway Administration (FHWA).
- Universities and academia.
- National organizations.
- Vehicle manufacturers and original equipment manufacturers (OEMs).
- Private consultants.

Invitees were asked to indicate their interest in serving in either or both of the following roles:

- Virtual stakeholder—receive project updates from the research team and potential opportunities to provide input at critical points during the project.
- Workshop attendee—participate in a small in-person workshop to discuss project areas relevant to AVs and infrastructure and develop a list of prioritized research topics.

Invitees were given the opportunity to request removal from the email list if they did not wish to be involved.

The workshop was designed to facilitate group discussions of major issues and challenges facing the operation of vehicles with engaged driving automation features that align with Level 2 and Level 3 of SAE's driving automation taxonomy, herein referred to as SAE Level 2 and Level 3 AVs, on roadway infrastructure. The research team maximized in-person participation by strategically choosing a date and location convenient for invitees attending the 2020 Transportation Research Board (TRB) Annual Meeting. Project funds were allocated to assist some workshop attendees with scheduling or modifying their existing travel plans to attend the workshop. The research team also reserved a conference line; however, no one was available to attend remotely.

The research team organized the workshop agenda (appendix B) in three parts: introduction, small group activity, and prioritization and wrap-up. The small group activity was included to encourage all participants to share ideas. The research team also created a list of questions to help facilitate discussion during the small group activity (appendix C).

As the research team finalized workshop details, they shared updates via email with invitees interested in serving as a workshop attendee and requested they confirm their attendance. One week before the workshop, the research team distributed the final agenda and a list of discussion questions to workshop attendees and those that could not attend but wanted to provide feedback via email.

WORKSHOP DETAILS

The following list provides information about the workshop:

- Title: AV Human Factors Safety Issues on Infrastructure Workshop.
- Location: Marriott Marquis, 901 Massachusetts Ave. NW, Washington DC, 20001.
- Time: 8:00 am–12:00 pm, EST.
- Date: Thursday, January 16, 2020.

A total of 18 individuals representing State DOTs, FHWA, universities, and private consultants attended the workshop. A list of attendees is available in appendix A. The next sections detail workshop activities and outcomes.

INTRODUCTION AND OPENING PRESENTATION

After a brief welcome from FHWA, attendees were asked to sign in and introduce themselves by stating their organization and area of expertise. The research team then delivered a brief presentation introducing the project and its goal to identify and investigate human factors safety challenges associated with SAE Level 2 and Level 3 AVs interacting with roadway infrastructure. The presentation included reviewing SAE Levels of Driving Automation and the importance of the driver, meaning the human in the vehicle supporting the driving task, in responding to or understanding the interactions between three key pieces: SAE Level 2 and Level 3 AVs, infrastructure, and other road users (SAE J3016 2018). Additionally, the research team shared three major challenge areas identified in the literature review and gap analysis: physical infrastructure (e.g., bridge and pavement life, geometric design), traffic control devices (TCDs) (e.g., pavement markings, signage, traffic signals), and transportation systems (e.g., throughput, traffic management, travel-time reliability).

Following the presentation, attendees shared knowledge of related projects in the fields of safety, AVs, and human factors. An annotated list of projects appears in appendix D.

SMALL GROUP ACTIVITY

After the research team provided an overview of the small group activity, attendees were asked to create three groups of six to develop research questions. Groups were self-selected and based largely on where attendees were already seated throughout the room. However, they were asked to avoid forming homogenous groups; the diversity of the attendees made this easy to achieve. Each group was provided markers and paper easels to document the research ideas they generated during the small group discussion. The activity lasted approximately 55 min.

Workshop attendees were encouraged to consider and organize their topics based on the three major challenge areas identified in the literature review and gap analysis. To develop their topics, groups were asked to consider the interactions between the three high-level categories, the role of the driver, and their potential implications on safety. A discussion guide (appendix C), which was provided to each participant, included anchor questions regarding these topics.

CHAPTER 3. WORKSHOP OUTCOMES

ACTIVITY REPORT OUT

Following the small group activity, one member of each group reported the outcomes of their discussion, which was then followed by a group discussion involving all attendees. The following sections contain the major questions and topics presented during the small group activity.

Again, this report uses the term AV to refer to a vehicle equipped with a driving automation system that has at least one driving automation feature engaged. As defined in SAE J3016 (2018), a conventional vehicle is "a *vehicle* designed to be *operated* by a *conventional driver*[1] during part or all of every *trip*."

Physical Infrastructure

The following list is an overview of the major questions and topics on physical infrastructure presented during the small group activity or that arose from the group discussion:

- AVs may be able to use lanes that are narrower than current lane-width standards. How narrow is too narrow? What is a driver's or occupant's comfort level with narrower lanes?
- Will changes need to be made to geometric design practices? Current geometric designs accommodate a driver's perception–reaction time of 2.5 s. Will this be adequate for a distracted driver?
- What are some of the impacts of AVs on pavement durability and maintenance schedules? How will a driver react to mitigation techniques (e.g., lane position–staggering algorithms)?
- How will AVs perform on roadways with general pavement wear, such as potholes or lane rutting? Will an AV be able to alert the driver to take over in time if pavement conditions are too poor for the system to properly operate?
- How will AVs perform on unstandardized and/or unregulated roads, such as parking lots?
- How will AVs identify their limitations during unexpected situations, and how will they communicate them to the driver?
- How will an AV know that a curve ahead has black ice? Will this situation result in a takeover-request duration that is not long enough for a driver to react?
- Current roads are designed for higher speeds than the posted speed limit. How will an AV handle situations where conventional vehicles are operating above the posted speed limit based on the roadway geometry?
- Will a lane dedicated to SAE Level 3 AVs require different geometric design features?

[1] A conventional driver, as defined in SAE J3016 (2018), is "a *driver* who manually exercises in-*vehicle* braking, accelerating, steering, and transmission gear selection input devices in order to *operate a vehicle*."

- How will AVs negotiate center two-way left-turn lanes with another vehicle (AV or conventional vehicle)? How will AVs communicate with other vehicles?
- Changes in object-height detection may be needed to facilitate better machine-vision detection of a greater variety of objects in the environment.
- Consider standardization of operational design domains (ODDs) and roadway-type definitions. Traveling 55 mph on a controlled-access highway can have different safety considerations, such as navigating around a slow-moving tractor, than traveling 55 mph on a two-lane rural road. How will an AV distinguish the two roadways, and how will the AV communicate to the driver that it recognizes and understands the situation?

TCDs

The following list is an overview of the major questions and topics on TCDs presented during the small group activity or that arose from the group discussion:

- Greater TCD standardization may facilitate better AV operations. (A National Committee on Uniform Traffic Control Devices Task Force provided recommendations on this topic in 2020.)
- Will a TCD designed for better AV comprehension also be beneficial for a driver? Could the TCD designed for better AV comprehension pose driver-comprehension issues?
- Will AV-only signage be needed? How will a driver interpret AV-only signage? Will the addition of AV-only signage lead to excessive sign clutter?
- Will conflict exist between what a sign indicates and the AV's interpretation? How will a driver know if this conflict occurs?
- Standard in-vehicle icons should be consistent with the *Manual on Uniform Traffic Control Devices* (MUTCD) (FHWA 2012).
- How will a driver know that the AV has detected and comprehends a TCD? What level of information regarding system confidence should be provided to the driver?
- What if an AV knows more information about a TCD than the driver? For example, an AV approaching a signalized intersection may begin to decelerate while the signal is green because it knows, via a signal phase and timing message, that the signal will change phases before the driver can clear the intersection. Will the driver interpret this as a system failure?
- Will designs of work zone TCDs need to be changed? Will drivers understand these changes?
- What are the effects, if any, of colored pavement markings on AVs?
- Will drivers understand new pavement markings designed for AV comprehension, such as hatched gore areas and skip lines at exits?

Transportation Systems

The following list is an overview of the major questions and topics on transportation systems presented during the small group activity or that arose from the group discussion:

- How will interactions between AVs and conventional vehicles influence driver behaviors? Will a mixed fleet encourage behaviors like aggressive following distances and social mimicry? What are the network effects of these interactions and behaviors?
- What are the network effects of takeover requests? Will the transfer of control result in reduced speeds or lane variability that will have more extensive network effects?
- How will AVs handle traffic delays? What are the network effects?
- Will AVs be allowed to speed or will they be required to adhere to the posted speed limit? What are the possible network effects of speed differentials between AVs that cannot speed and drivers who can?
- Will standards exist for the acceleration and/or deceleration rates of AVs? How will occupants of AVs and other road users accept these rates? Will uncomfortable rates cause drivers of AVs to take control more frequently because of frustration and/or loss of trust? Will standard rates cause conventional-vehicle drivers to perform more aggressive maneuvers around an AV?
- What kind of distances around a vehicle (an AV or conventional vehicle) will the occupants accept before they get too anxious?
- How will AVs influence a driver's trip planning? Will AV drivers care less about traffic delay and congestion if it means they can use that time for activities other than driving?
- What are the minimum and maximum following distances with which drivers of both AVs and conventional vehicles will be comfortable? How will speed and environmental factors affect drivers' comfort and/or acceptance?
- Will platoons of AVs following one another closely cause situations where other vehicles (both AVs and conventional vehicles) cannot enter and/or exit the highway?
- Consider the safety of vulnerable road users (VRUs) (e.g., pedestrians, bicyclists) when interacting with AVs. The goal of vehicle automation is to have 100-percent market penetration of vehicles with full driving automation (SAE Level 5). Even in a non-mixed-use environment, there will be interactions with pedestrians.
    - How will an AV negotiate yielding with pedestrians/bicyclists?
    - How will an AV identify right-turn conflicts with pedestrians/bicyclists?
    - How will an AV give bicyclists adequate space when overtaking?

Other Discussions or Topics

The following list is an overview of other major questions and topics presented during the small group activity or that arose from the group discussion:

- Consider general safety concerns related to an SAE Level 3 AV. A driver's overreliance on SAE Level 3 vehicle driving automation features may result in the degradation of their skills. Drivers may be unprepared to take over in unexpected safety critical situations or difficult ODDs.

- It is critical that OEMs and Federal agencies, such as FHWA and the National Highway Traffic Safety Administration, work together to define issues for AVs and real-world frameworks with solutions.
- Vehicle technologies will have evolved by the time AV or ADS guidelines are implemented. How can guidelines be designed so that they are still relevant and/or appropriate in the future?
- Under what conditions or point in development and deployment will drivers and roadway users feel comfortable letting an AV control certain maneuvers or interact with other roadway users?
  - A driver might engage automated driving features during basic travel, but during a nonrecurring event (e.g., event traffic, work zone, incident), they might prefer to take control.
  - A driver might be comfortable with an AV when driving solo but not when driving with a young child or an infant in a car seat.

TOPIC PRIORITIZATION

Following the small group activity report outs and stakeholder discussion, attendees were given a break. During this time, the research team consolidated the research ideas and discussion topics. These topics were then reviewed during a large group discussion and modified until everyone felt that the final 13 high-level research topics captured the groups' ideas adequately.

Next, the group completed the topic-prioritization activity, in which they were asked to vote for research topics they deemed most important to address. Each attendee was allowed three votes to be distributed as they deemed fit (i.e., they could cast all three votes on one topic, if desired). As 4 attendees had to leave the workshop before the topic-prioritization activity, a total of 42 votes were cast. The research team tallied the votes and shared the results with the group. The prioritized list of research topics and a summary of related questions is as follows:

1. Mixed-fleet acceptance and traffic behavior.
   - How will the behaviors of AVs and conventional vehicles influence roadway capacity, travel-time reliability, and throughput? For example, will longer following gap distances or deceleration distances disrupt traffic flow or negatively influence public acceptance and trust of AVs?

2. Pedestrian–AV and bicyclist–AV interaction.
   - How will an AV navigate situations that often rely on social cues or expectations, such as yielding, navigating right-turn conflicts with bicyclists, and providing appropriate buffer space when overtaking? How will VRUs and AVs understand each other's intended behaviors?

3. Modification of work zones for AVs.
   - How will AVs handle the temporary and variable environment of a work zone, which has a different set of operational rules and expectations? Whereas humans can easily adapt to narrowed lanes and sign clutter, how will an SAE Level 2 or Level 3 AV respond to these environments?

4. AVs having different information than the external environment.
   - Connected AVs may have access to information before a driver, or an AV may have information that does not match the environment (e.g., a different speed limit based on an outdated map). How might these situations affect driver trust and system use?

5. AV understanding of specific infrastructure.
   - What is the capability of an AV to respond to specific types of infrastructure intended for different situations, such as bike lanes, marked trail crossings, or unconventional interchanges?

6. Speed differentials between AVs and conventional vehicles.
   - If AVs follow speed limits more closely than drivers, how could this affect other drivers' choices to follow or overtake AVs? What are the network effects of these interactions and behaviors?

7. Comfort of drivers and passengers with changes in geometric design for AVs.
   - Will conventional-vehicle drivers or passengers of AVs find roadways specifically designed to maximize AV operation (e.g., narrower lanes) uncomfortable?

8. AV-specific lanes.
   - To avoid a mixed-fleet environment, will AV-specific lanes need to be designed? How could traveling only within a homogenous group of AVs affect driver use or trust of AV systems?

9. AV communication with drivers.
   - How will AV drivers understand the behaviors to expect from an AV? How much and in what ways should AVs communicate their awareness of the environment and intended actions to the driver?

10. AV behavior off public and/or regulated roads.
    - How will an AV navigate areas where road regulations and/or TCDs are arbitrary and/or unstandardized (e.g., schools, malls, parking lots)? How will an AV operate in areas with minimal signage or road markings?

11. Jurisdictional responsibility for standardization.
    - Variations in TCDs, road geometry, and regulations may make it difficult for AVs to operate safely and effectively across localities. Who is responsible (e.g., Government, third party) for pioneering and enforcing improved standardization?

12. AV negotiation behavior.
    - How will AVs negotiate behaviors like merges or cut-ins with conventional vehicles? How will an AV respond to a four-way stop when multiple vehicles arrive at the same time?

13. Human understanding of and reaction to TCDs designed specifically for AVs.
    - Will drivers understand or be confused by signage or lane markings modified to be more visible to AVs? For example, will drivers interpret extended lane markings at gores as prohibitive?

After the topic-prioritization activity, attendees joined in a final discussion of the results and the workshop was adjourned. During the final discussion, everyone agreed that topics that received few or no votes were not unimportant but rather already being researched or less urgent when considering a near-term study. Attendees indicated that AV negotiation behavior received no votes because it relates to mixed-fleet acceptance and traffic behavior. Additionally, FHWA shared that the feedback from the workshop may be used to guide future projects related to AVs and needed research tools.

APPENDIX A. SUMMARY OF ATTENDEES

Table 1 summarizes the number of attendees based on organization type and includes specific areas of expertise represented.

Table 1. Summary of workshop attendees.

Number of Attendees	Organization Type	Areas of Expertise
6	State DOT or department of public safety	Transportation engineering, transportation safety, mobility, connected AVs, national policy, crashes
4	University or academia	Human factors, human–machine interfaces, trust in automation, AVs, driving simulations, human–automation interaction
2	National organization	Transportation policy, technology, biking
2	Private consultant	AVs, geometric design, human factors
4	FHWA	Bicycle safety, TCDs, work zones, MUTCD, AVs, infrastructure, geometric design, highway safety, intersections

APPENDIX B. AGENDA

Table 2 contains the agenda of the workshop. Please note, the research team provided additional time for the small group activity, so the time in the agenda differs from the time in the report narrative.

Table 2. Workshop agenda.

TIME:	TOPIC:
8:00–8:15	Check-in
8:15–8:35	Welcome and Introductions • Welcome attendees. • Attendees will share their name, organization, and area of expertise.
8:35–8:55	Background Presentation • Introduce the research topic and goals. • Share results of Literature Review. • Address audience questions/invite related project updates.
8:55–9:00	Introduce Small Group Breakout Activity • Provide discussion topics and objective of activity.
9:00–9:05	Short Break & Transition to Groups
9:05–9:50	Small Group Breakout • Attendees will discuss the following topics and formulate research topics/questions and human factors issues related to the safe operation of automate vehicles as a function of roadway infrastructure: o Physical infrastructure. o TCD. o Transportation Systems.
9:50–10:40	Small Group Report Outs and Discussion • Each small group will present on their research topics and human factors issues. • Larger group discussion. • Generate consolidated list of topics.
10:40–10:50	Break/Prioritization Activity Prep
10:50–11:05	Prioritization Activity • Attendees will prioritize research topics. • Summarize prioritization of research topic. • Gain consensus from attendees.
11:05–11:25	Research Discussion • Discuss potential research methodologies to address prioritized research topics.
11:25–11:30	Wrap-up and Final Comments • Attendees will have an opportunity to share any last comments. • Overview of next steps.

APPENDIX C. DISCUSSION GUIDE FOR THE SMALL GROUP BREAKOUT

Objective: Formulate potential research topics and/or questions regarding human factors safety issues associated with the safe operation of Level 2 and Level 3 vehicles as a function of roadway infrastructure.

Consider potential:

- Effects of AVs on infrastructure;
- Effects of infrastructure on AV operations;
- Interactions between AV user, AV system, and other road users (including manual vehicle users);
- Solutions/mitigations to anticipated issues and how to ensure success of applied solutions;
- Influence of connected vehicle technology.

Below, describe potential research questions for each topic:

1. Physical infrastructure (bridge and pavement life, geometric design, etc.).

2. Traffic control devices (pavement markings, signs, traffic signals, etc.).

3. Transportation systems (throughput, traffic management, travel time reliability, etc.).

APPENDIX D. ANNOTATED LIST OF RELATED PROJECTS

The following list is an overview of the related projects the workshop attendees shared.

- The University of Wisconsin is exploring the consequences of drivers resuming control of an AV, including trust and mitigation of traffic flow problems that may occur when a driver responds to a takeover request. The university is developing improved microsimulation models, although the project is in its early stages.

- The Texas A&M Transportation Institute (TTI) partnered with the Virginia Tech Transportation Institute for the Safety Through Disruption National Safety University Transportation Center is funding several projects related to automation. A list of current projects is available online (TTI 2020). TTI previously conducted a project on pavement rutting and lane wandering, which included modeling of wandering algorithms and predicting when rutting depths would reach hydroplane risk (TTI 2019). TTI also completed a National Cooperative Highway Research Program (NCHRP) project (20-24(112)) on road classification systems that involved examining the geometric and road features that enable different levels of connectivity and automation (TRB 2020b). TTI also conducted an NCHRP project (20-102(06)) on road markings for machine vision for which a published report is expected soon.

- There are additional NCHRP projects related to the topics discussed at the workshop, including the following:
    - Assessing the Impacts of Connected, Automated, and Autonomous Vehicles on the Future of Transportation Safety (Jointly Funded with NCHRP 17-91) (TRB 2020a).
    - Impacts of Connected and Automated Vehicle Technologies on the Highway Infrastructure (TRB 2020c).
    - Infrastructure Modifications to Improve the Operational Domain of Automated Vehicles (TRB 2020d).

- The Minnesota Department of Public Safety is mining naturalistic driving data to investigate vehicles overtaking bicyclists under different conditions and road types. The department is also conducting another project that explores interactions between vehicles and pedestrians and vehicles and bicyclists at intersections, including the role of body language in signaling right-of-way and yielding, using large Level 4 datasets.

- Wyoming DOT is conducting a connected vehicle pilot in which they are exploring automation in commercial motor vehicles, such as semitrucks, using a driving simulator (Wyoming DOT 2020). The DOT is also investigating different human–machine interfaces for driver takeover and nonrecurring events.

- Colorado DOT is exploring variable speed limits (VSLs) for transportation systems management operations (Colorado DOT 2019). The DOT is investigating the influence of VSLs on dynamic lane-use control and hard shoulder running (i.e., using shoulders as an extra lane during weather or congestion).

- The University of North Carolina Highway Safety Research Center conducted a synthesis project on AVs in school zones with a focus on children who walk and bike to school. The project focused generally on human–vehicle interactions in less structured/regulated travel areas. The report for this project is pending. Other ongoing projects at the university are exploring North Carolina’s data readiness for AV deployments, including vehicle, infrastructure, and public acceptance perspectives.

- The University of Michigan Transportation Research Institute is conducting research on AV communication and interaction with VRUs, including projects on how pedestrians and bicyclists interact with drivers and how pedestrians interact with SAE Level 4 shuttle buses.

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