March 5, 2018

Docket Management Facility
U.S. Department of Transportation
1200 New Jersey Ave. SE
W12-140
Washington, DC 20590

Re: Docket No. FHWA-2017-0049

The American Council of Engineering Companies (ACEC) – the voice of the nation’s engineering industry – respectfully submits the following comments in response to the Request for Information on Automated Driving Systems (ADS). These responses reflect the feedback of expert practitioners working on ADS implementation issues for several public and private sector clients around the world.

1. What roadway characteristics are important for influencing the safety, efficiency, and performance of ADS? Are there certain physical infrastructure elements (e.g., lane markings, signage, signals, etc.) that are necessary for ADS? If so, what current challenges exist for ADS to interpret them? Are these characteristics important for all levels of automation, or only specific levels?

As a starting point, FHWA and state and local transportation agencies should consider the extent of traditional ITS infrastructure deployment in the context of reviewing ADS preparedness. While this RFI is seeking ADS-specific input, deployment and operation of ITS infrastructure is a key to overall roadway safety, particularly in a mixed fleet of vehicles.

Considering ADS specifically, it is important to look at use cases when identifying the roadway characteristics that support them. For example, in many vehicles, lane keeping currently relies principally on camera technology. Therefore, the visibility of lane markings is important for this use case. NCHRP 20-102 has initiated research in this regard and should be used as a resource.

Similarly, sign quality and traffic signal configurations are important for ADS. While most ADS vehicles have embedded databases of traffic control signage, there are many special cases such as parking restrictions which may require additional technology, particularly Level 4 driverless systems, to expand their Operational Design Domain (ODD).

Current challenges include:
- Snow cover and wet pavement can limit visibility of pavement markings.
- Direct sunlight can temporarily “blind” the cameras.
- Current sensors and software in the vehicles can only interpret what is within range of the sensors. Confidence increases as the vehicle gets closer to objects. Thus, sensor range and
confidence levels can diminish if signs and signals are not maintained properly. This also applies to obstacles in the vehicle path. At long distances, a plastic grocery bag may look like a person wearing a flowing white gown. As the vehicle gets closer, confidence levels increase, and the vehicle will understand the situation better in order to behave in the proper and safest manner. Vehicle wraps and certain billboards, particularly ones with images of humans, animals, and other vulnerable road users can confuse object detection and avoidance software.

- GPS signal quality also affects performance of these systems. ADS rely on location accuracy, especially at higher levels of automation. In urban canyons, parking structures, tunnels, etc., GPS signal loss or disruption can be problematic. GPS repeaters and differential correction beacons can support location accuracy for ADS.

- Horizontal and vertical curves can also be challenging for ADS. When a vehicle is driving down a steep hill, it may “see” a wall in front of it. The vehicle must be capable of understanding that the road is turning “upward” and does not pose a threat. Similarly, if a vehicle is about to crest a steep curve, it sees nothing but sky in front of it. Such situations will likely rely on HD maps or they may force the vehicle to slow down significantly. If the vehicles slow down when faced with such situations, safety issues may occur, especially if other vehicles are not equipped to respond to the slowing vehicle in a timely manner. Horizontal curves pose similar challenges for ADS. Lane markings can support navigation through horizontal curves, but the factors noted above related to visibility of lane markings will be critical, particularly when curve configurations are different than normal, such as in work zones.

- In the future, electric vehicles will be far more common, but infrastructure is a constraining factor. Additional charging facilities and grid modernization are necessary to support future automated vehicles. This is particularly true for driverless vehicles which will have no attendant to attach the charging tether to the charger. Inductive charging and automated charging connections will need to be developed. Unless such charging facilities become as ubiquitous and distributed as current gasoline filling stations, much additional VMT will be generated by AVs “returning to base” to be re-charged.

- Vehicle sharing (both car-pooling and sequential sharing, i.e. taxi operations) is also likely to increase. This has significant impacts on the infrastructure, particularly for the transition of parking infrastructure from side-by-side parking to nose-to-tail configurations.

- Platooning operations are another short-term use case that has implications for design. Designated lanes and lane management solution may be required. Truck platooning is a likely near-term use case. It may be necessary to move trucks into left lanes of limited access highways to allow safe ingress and egress from such facilities. NCHRP 20-102 has initiated research on guidance in this regard.

- Work zones are perhaps one of the most critical challenges for ADS since cones, barrels, jersey barriers, and other traffic control devices (and workers) will be present in areas that are not captured in embedded HD maps. A variety of technology solutions (smart cones, wearables, mini-map broadcasts, automated updates of work zone geometries, etc.) may be necessary to improve the ability of ADS in work zones.

While fixed infrastructure improvements may be necessary to ensure ADS safety, improved digital infrastructure to support vehicle-to-infrastructure communications at traffic signals and in other critical circumstances will be an important enhancement in addition to sensor-based
technologies to improve safety of the operating environment. Higher levels of automation will be less dependent on lane markings, signs, and signals as high-definition mapping, improvements in location accuracy, V2I/V2V/V2X solutions and enhanced AI come into play. For maximum safety benefits, connectivity among the vehicles and the infrastructure is required. As the penetration of Level 4-5 vehicles increases over the next two to three decades, V2X standards-based solutions will likely become more critical.

It will be important for public agencies and providers of ADS to collaborate on connectivity solutions to support enhanced safety and mobility solutions, especially at higher levels of automation. Further, sustained, honest, and open dialogue is needed between technology developers and infrastructure owner/operators to better understand the needs of ADS and have a meaningful path to meeting those needs.

2. What challenges do non-uniform traffic control devices present for ADS technologies and how does this affect the costs of ADS systems?

While more sustained, honest, and open discussion is needed between ADS developers and infrastructure owner/operators on this topic, automakers appear intent to operate ADS fleets in confined areas where infrastructure and mapping assets meet sufficient standards. As such, uniformity of traffic control devices across jurisdictions is critical in the short term to promote broader operational boundaries. This should be an emphasis point for FHWA, consistent with its traditional role. Increased standardization, and further limitation of allowable design variances of traffic control devices will improve both human driving and ADS.

However, the incremental cost of software in ADS to handle multiple device configurations is likely much lower than the cost to infrastructure owner-operators to replace and reconfigure existing traffic controls. For example, it is well known in machine vision technology that round shaped signs are much more easily identified than rectangular shaped signs since so much of the built environment is rectangular rather than circular. Imposing new requirements on owners (e.g. replacing all or some rectangular traffic control signage for circular designs) for the purpose of reducing costs of ADS developers to handle a variety of situations is probably not prudent at this time.

3. How does the state of good repair (e.g., pavement and road markings quality) impact ADS, including technology or safety costs, if at all?

As noted in the response to question #1, quality road markings and signs are critical at this time since many ADS depend on camera technologies. Some testing is occurring in sites which specifically include infrastructure maintenance issues to determine the ability of ADS to operate in those conditions. It will be critical for this research to be shared to understand the constraints this may pose for infrastructure owner/operators to prioritize maintenance activities.
4. **How should FHWA engage with industry and automation technology developers to understand potential infrastructure requirements? Are there specific issues that FHWA should engage with industry directly?**

U.S. DOT should continue to facilitate a dialogue and share generalized feedback from ADS developers (rather than technology-specific or proprietary feedback). While testing around many of these questions is on-going, sharing results of this research in as close to real-time as possible will be important, as these developments are moving so quickly. To be meaningful, this dialogue must find a way to aggregate findings and input such that it does not introduce competitive concerns with developers and can be more unfiltered.

The AV Proving Grounds offer an excellent opportunity for collaboration, but also to identify infrastructure use cases for ADS. So far, the focus has been on the vehicle, not the infrastructure. Flexible test environments that support a variety of infrastructure characteristics, traffic control strategies, lane management solutions, connectivity solutions, parking and queuing, curbside, solutions, curvatures, etc. are needed to support an integrated environment for automated driving. Urban and suburban environments need much more additional attention than limited access highways as the variety of facilities across the U.S. is considerable.

Federal policy needs to focus more on the infrastructure requirements for automated driving. For example, *Automated Driving Systems 2.0: A Vision for Safety* focuses primarily on the vehicle and assumes the status quo regarding the operational design domain. It also ignores vehicle connectivity as an integral part of the future automated driving environment. The policy guidance references the following elements for the operational design domain as minimums:

- Facility Type
- Geographic Area (Urban/Rural)
- Speed Range of Vehicles
- Environmental Conditions

However, the operational design domain must include these elements:

- Level of Connectivity (V2I, V2X)
- ITS and Traffic Management Infrastructure
- Communications/Network Infrastructure
- Electrification Infrastructure
- Data Management Environment
- Inter-Modality
- MaaS Environment
- Regulatory / Enforcement Considerations
- Roadway Conditions
- Mapping & Location Services

U.S. DOT and its modal agencies should continue to hold listening sessions and other public meetings, as well as convene focus groups, conduct surveys, and circulate additional requests for comments and public input to ensure broad inclusion of interested stakeholders and affected groups.
5. What is the role of digital infrastructure and data in enabling needed information exchange between ADS and roadside infrastructure? What types of data transmission between ADS and roadside infrastructure could enhance safe and efficient ADS operations? What type of infrastructure and operations data, if available, would help accelerate safe and efficient deployment of the ADS on our Nation's public roadways? How might the interface between ADS and digital infrastructure best be defined to facilitate nationwide interoperability while still maximizing flexibility and cost effectiveness for ADS technology developers and transportation agencies and minimizing threats to cybersecurity or privacy?

V2I and V2X connectivity is an important element to enhance the safety of ADS, as well as to enable other downstream opportunities for system efficiency and improved mobility. The current view of ADS being entirely reliant on sensor-based systems and mapping is limited in the same way that a human driver is limited from “seeing” things beyond the field of sensor (or eye) view which may pose safety threats. While computer drivers will not be distracted the way that human drivers can be, the human brain is still amazingly capable of processing nuances of other drivers’ intent in ways that are challenging to embed in artificial intelligence rules that mimic what capable, highly experienced defensive drivers generally practice. This will be particularly critical during the long transition period towards automated driving, when a mix of vehicles exist on the roadway. Further, digital exchange of information from infrastructure assets such as traffic signals can greatly increase the capability for an ADS to support decision-making.

Foundational needs for public agencies include:

- Ensuring the security of data transmission from infrastructure to vehicles.
- Expansion of their communications and traffic control infrastructure. This may include establishing partnerships with commercial communications providers for future 5G capabilities and modernization of traffic signal controllers.
- Strengthening data management capabilities (collect, transmit, store, aggregate, analyze, disseminate, report). This could be through partnerships with third-party providers of cloud-based services.
- Strengthen technical capabilities of staff and workforce for operating and maintaining the infrastructure.

FHWA should further promote the use of the guidelines in FHWA-JPO-18-629 and other V2I-related resources.

Security and Privacy
Security and privacy must be designed into the connectivity solutions. This will be a continuing challenge as the level of connectivity increases.

Plus, agencies must look at the physical security of their networks. Traffic control systems are potential points of vulnerability for local networks, especially in a connected vehicle environment. This is exacerbated by the fact that most roadside cabinets can be accessed using a standard #2 key. This must change in the future. Cyberlocks and other physical security options
are available to agencies from the roadside back to the office to secure their systems from such vulnerabilities.

**Data Management Challenge**
Offering open data about real-time traffic conditions and transportation options will spur innovative ways to get information into the hands of travelers, opening up new possibilities. Use of data analytics by agencies and by individuals will help shape the future of road and vehicle technology. However, data management and preparedness for data input is one of the greatest challenges facing most public agencies already, and this will only get more challenging with data from connected vehicles.

With data streaming from every connected vehicle on the road, even modern networks and storage systems will be overwhelmed. Public-private partnerships will become important to harness the “big data” that vehicles and intelligent infrastructure are collecting. The key to managing this information and data collection will be a focused set of performance measures to guide state and local programs so that relevant information is kept at the forefront and extraneous information does not distract from analysis goals. FHWA should continue in earnest to develop open source data management platforms for handling the future information from CAVs such as suggested in FHWA-JPO-18-625 and FHWA-JPO-18-626. FHWA can also provide public sector guidance on how transportation agencies can prepare for real-time data flows generated through vehicle-infrastructure connectivity.

**Workforce Challenges**
Building and maintaining tomorrow’s transportation system will require system integrators, network designers, network security specialists, data analysts and software engineers. There is currently a lack of skilled staff to support data management and analysis of all the data that is coming in today, and those needs will continue to multiply. This is especially true inside public transportation agencies, where the focus for many decades has been on the design and maintenance of traditional infrastructure. Workforce development programs have begun to fill this gap, but skilled labor remains a risk for many agencies across the country. Open development platforms such as Linux provide opportunity for scalable solutions like never before, but skilled labor is currently spread thinly between many private tech industries.

In addition to the lack of skilled labor, there is a lack of resources to collect, transmit, aggregate, store, analyze, and transform data into actionable information. From network infrastructure with appropriate throughput to storage media for Terabytes and Petabytes of information, major upgrades will be needed to store and process transportation data. This data will empower users—government workers and travelers alike—with information for decision support systems such as road maintenance and for mobility awareness like travel times and options.

6. **What concerns do State and local agencies have regarding infrastructure investment and planning for ADS, given the level of uncertainty around the timing and development of this technology? How should FHWA engage with its State and local partners as they consider impacts on infrastructure, transportation funding, finance, and revenue? Are changes to any of the programs that comprise the Federal-aid**
Highway Program needed to enable State and local agencies to more effectively make infrastructure investments to support deployment of ADS?

Most state and local agencies seem to generally support ADS introduction as an effective means to improve safety. However, there are significant questions about how and where to invest to meet those needs, with limited funding already stretched. In addition, the trends towards electrification and shared fleet-type arrangements have brought about uncertainty as to long-term revenue implications, currently largely supported by fuel taxes.

While FHWA has engaged in the development of frameworks for planning with these uncertainties, improved outreach and direct engagement with state and local agencies to see how those tools and approaches can be applied would support improved and more consistent response. Scenario-based planning, including shortened planning horizons with greater confidence levels in predictions and forecasts, is a useful tool for agencies and their stakeholder partners. In addition, more research at the national level on potential impacts to fuel-based revenue sources given the trends towards electrification and potential reduction in total fleet sizes would help to improve a national dialogue, even if the solutions must be addressed in part at the state and local level.

Finally, in discussions with many agencies, there continues to be a lack of clarity about the eligibility of technology, infrastructure, and communications improvements under the FAHP and related funding programs. Further dialogue and clarification of federal eligibilities with state and local agencies to understand these questions and to respond in a manner supportive of preparation for ADS would be helpful.

7. Are there existing activities and research in the area of assessing infrastructure-ADS interface needs and/or associated standards? What is the current thinking on where potential revisions may be necessary? How should FHWA work with existing research partners (e.g., American Association of State Highway and Transportation Officials, Transportation Research Board, etc.) in sharing research results and information?

Significant research activities are on-going in this area, but they are underfunded in the United States when compared to the European Union, individual countries within Europe, China and Japan. While TRB is in the process of updating its research roadmap for automated and connected vehicles, the funding level is substantially lower than other countries (~$10M as opposed to $100M+ investments by other nations). In addition to uncertainty about timing, the most significant gap currently appears to be the role of infrastructure in supporting ADS operations, and how critical it will be for state and local agencies to take action to enable ADS. Facilitating on-going dialogue on this topic as talked about in previous questions would be extremely beneficial to close this gap.

FHWA should also work with SAE, IEEE, and automakers to understand the nuances of ADS for infrastructure design criteria. The AV Proving Grounds offer an opportunity to do this, but the FHWA must be more actively involved to support such partnerships.
8. What are the priority issues that road owners and operators need to consider in terms of infrastructure requirements, modifications, investment, and planning, to accommodate integration of ADS and to derive maximum system efficiency benefits from ADS additional capabilities?

There continues to be a lack of clarity from infrastructure owner/operators about what those priority issues should be, both in terms of specific actions and timing of those actions. Further, these answers will likely vary between agencies based on size, capacity and location. Again, the lack of clarity on this answer points to the need for a facilitated dialogue between infrastructure owner/operators and ADS developers.

This challenge is compounded by the current structure of infrastructure ownership, where many layers of state and local governments are responsible for operations and maintenance of distinct elements of infrastructure assets. The federal government can help play a role in standardization and promoting technology harmonization and data/control sharing strategies.

9. What variable information or data would ADS benefit from obtaining and how should that data be best obtained? Examples might include information about zone locations, incidents, special event routing, bottleneck locations, weather conditions, and speed recommendations.

All these types of dynamic data must be obtained and shared with ADS to realize full safety benefits. FHWA can play a role in advancing a ubiquitous V2X/V2I platform for all vehicles to address connectivity in a consistent and reliable format and frequency.

There are significant attributes of the transportation system which vary in time and could provide benefit to ADS. Many of these high-value features have already been mined through private services leveraging probe data, crowd-sourcing and cellular communication to reach users.

More complicated is the question of what data do infrastructure owner/operators uniquely have access to or control which would benefit ADS, and how can that be disseminated. First and foremost, traffic signal data is of critical safety and mobility value, and can only be shared via low-latency, short-range communications to gain full safety benefits. These systems would also likely be the easiest to deploy, as traffic signals currently have power, and many have communications systems already in place. Further, standards govern the output directly from the traffic signal controller which do not require any other manual or system intervention to create this message.

Other examples differ in terms of how the data would be acquired by the infrastructure owner/operator in the first place to communicate out. Information which can be generated in an automated fashion – such as speed recommendations, etc. – will be easier to communicate than work zone information, which may require manual input of data to communicate it outward to ADS. Each will present challenges at scale, and priorities must be established to support agency decisions in the future. Innovations in dissemination of work zone locations and configuration
should be one of the FHWA priorities as standardization across local and state agencies will need to be achieved for maximum impact.

10. **What issues do road owners and operators need to consider in terms of infrastructure modifications and traffic operations as they encounter a mixed vehicle fleet (e.g., fully-automated, partially-automated, and non-automated; cooperative and unconnected) during the transition period to a potentially fully automated fleet? What are likely the most significant impacts of ADS on other motorized and non-motorized users of public roadways? What plans do stakeholders have to address these impacts, and are there possible roles for road owners and operators to support the interaction of ADS with those users through infrastructure changes or operational strategies?**

These questions will likely only be answered with time and experience, and wholesale changes to the infrastructure to segregate ADS users from human-driven vehicles are unlikely to be feasible at any significant scale. Transit agency policies, technology, and operations will also need significant attention.

As such, consider early use cases, such as:
- Urban applications – shared use vehicles
- Intermodal facilities – first and last mile opportunities
- Residential and campus applications
- Highway maintenance operations
- Truck automation and platooning

All these use cases have implications for infrastructure modifications and traffic operations.

In summary, the challenges and issues for public agencies include:

**Technical Issues:**
- Interoperability and standards
- Implementation and support of specific applications & technologies
- Data management
- Data privacy
- Communications and network management
- Security management
- Local network security
- Technical obsolescence

**Institutional Issues:**
- Funding – shortfalls impact the operational capabilities.
- Education & workforce considerations – lack of staff with necessary technical skills.
- Business case – lack of benefit and cost information to support investment decisions.
- Data ownership – how to access it, who owns it, how do they support it?
- Liability – what is the risk and how does it get allocated?
- Forces outside their control – changing technologies and political climate leave public agencies feeling uncertain.
Operational Challenges:
- Education & workforce considerations – new skills needed in data analytics, IT, application support, software and new algorithms.
- Data management – big data from connected vehicles will challenge operational staff.
- Keeping up with advances – the operations environment will continue to evolve at a rapid pace.
- New partnerships and business models, both public and private.
- Giving up control – greater automation of public agency functions, greater empowerment of travelers, and impacts of connected automation.

Integration of ADS-equipped vehicles into the existing transportation environment will be challenging and disruptive to current paradigms. Engineering and operational concepts, performance measures, algorithms, the transportation workforce, design standards, traffic control systems, and policies must be addressed in a proactive way.

Thank you for your attention and consideration. We look forward to working with U.S. DOT and the modal administrations to advance ADS in a safe and effective manner.

Sincerely,

Matt Reiffer
Director of Transportation Programs