US NHTSA ADS Safety Assurance Framework ANPRM Response

SUBMITTED ELECTRONICALLY VIA REGULATIONS.GOV

Acting Administrator
National Highway Traffic Safety Administration
1200 New Jersey Avenue S.E., West Building
Washington D.C. 20590-0001

April 1, 2021

Re: NHTSA Advance Notice of Proposed Rulemaking, Framework for Automated Driving System Safety, NHTSA Docket No. 2020-0106, 85 Fed. Reg. 78058 (December 3, 2020)

Dear Acting Administrator:

The Institute of Automated Mobility (IAM) appreciates this opportunity to provide comments to the National Highway Traffic Safety Administration's ("NHTSA" or "Agency") advance notice of proposed rulemaking ("ANPRM") for the development of a framework for Automated Driving System ("ADS") safety. The IAM [Arizona Commerce Authority, 2021] was established by executive order in 2018 to "provide the technical guidance and coordination required to ensure the prudent implementation of safe, efficient automated mobility across Arizona". The safe introduction of ADS technology requires coordination between all members of the ADS community. The IAM is focused on the role of the infrastructure owner/provider and thus our response to this NHTSA request will be infrastructure oriented.

The IAM applauds the USDOT and specifically NHTSA for your posture towards ADS development. AV developers have appropriately been given the latitude to develop their ADS technology without regulatory oversight that would hamper innovation. AV developers have provided safety data under the Voluntary Safety Self-Assessment (VSSA) directive and NHTSA has worked to remove unintended and unnecessary regulatory barriers. Going forward, as ADS-equipped vehicles (hereafter referred to as AVs) are deployed in greater numbers, a mature safety assurance framework will need to be embraced by the ADS community. Defining this framework requires input from all corners of the community. The IAM supports NHTSA's timely release of this ANPRM for the establishment of a safety assurance framework that will, when ADS technology has matured appropriately, establish appropriate policy and regulation such as an FMVSS for ADS.

ADS development is rapidly advancing and Arizona is proud to be one of the states where significant development and testing is occurring. The IAM agrees with NHTSA that AV deployment (SAE levels L3 – L5) is likely to increase significantly over the next decade. The pace at which it is accepted and therefore, the pace at which it can positively impact transportation safety, directly depends upon how safely it is introduced. The IAM foresees an important role for infrastructure owners/providers in optimizing deployment safety. Infrastructure owners/implementers are uniquely positioned to contribute as follows:

1. Enhancement of roadway physical attributes such as clear signage and road markings so that they are optimized for AVs and remove any barriers.
2. Establishment of an affordable safety monitoring network at a representative set of points of interest across the infrastructure such as intersections, merge points, pedestrian walkways, etc., that allows ADS safety issues to be rapidly identified and addressed. A primary design focus is on the minimization of installation and deployment/maintenance costs.

3. Provision of low-latency, dependable wireless connectivity to enable V2I for operational safety data sharing, first responder coordination, construction zone management, vulnerable road user safety, roadway usage efficiency optimization, etc.

IAM research is focused on contributions 2 and 3 and is designed to inform the real-world implementation of effective, affordable infrastructure deployments at scale. We believe that such deployments can be fielded over the next 3-5 years and that they are essential for the safe introduction of AVs, closing the loop with AV developers to correct design shortcomings and collecting operational data to assess the maturity of ADS technology for broad deployment. AV developers must take all reasonable measures to ensure that their designs are roadworthy and safe before deploying them in appropriate ODDs; however, realistically, given the complexity of the real world, said designs will inevitably have shortcomings and should be matured over time for their full safety potential to be realized. Only by prudently introducing ADS designs into appropriate ODDs with close monitoring, can this design maturation process be conducted with maximum safety. Further, monitoring will be critical in perpetuity to ensure that unintended consequences resulting from future ADS advances and upgrades, as well as changes to the infrastructure, can be identified and addressed with expediency and effectiveness.

There is considerable debate within the research community about what level of wireless connectivity is required for ADS deployment. The failure of DSRC to transition from the research domain into mainstream deployment is illustrative of the challenges involved in deploying trustworthy, effective, safe and economical wireless communications. SAE J3216 defines four classes (classes A, B, C, D) of cooperative driving automation (CDA). The IAM's inclination is to implement the infrastructure component of class A as a placeholder that can be adapted to accommodate higher classes if they should become prevalent. The IAM is conducting research into the deployment of smart, cellular road-side units (RSUs) at our live test bed in Anthem, AZ, focusing on enabling the broadcasting of safety-relevant data from the infrastructure such as SPAT data and vehicle kinematics data collected during traffic monitoring. Further, IAM researchers are investigating the role of wireless communications in enhancing first responder safety and safe vehicle navigation through construction zones and temporary detours.

The eventual ADS safety assurance framework will impact the implementation and management of transportation infrastructure and is therefore of paramount importance to the IAM. The IAM looks forward to collaborating with NHTSA and the broader community to establish an ADS safety assurance framework and to provide guidance to AZ on how it translates into prudent infrastructure deployment. The IAM thanks NHTSA for the opportunity to share our philosophy on the role of the infrastructure in ADS safety and stand ready to provide further input upon request. We commend NHTSA for publishing an ANPRM that focuses the community on defining the regulatory framework that will eventually guide policy and regulation specification necessary for the safe widespread deployment of AVs.

Sincerely,

Marisa Walker, IAM Executive Director

Greg Leeming, IAM Technical Director

Question 1. *Describe your conception of a Federal safety framework for ADS that encompasses the process and engineering measures described in this notice and explain your rationale for its design.*

The IAM foresees a framework that establishes a productive relationship between AV developers and infrastructure owners in which AV developers are responsible for establishing rigorous, comprehensive safety assurance cases of their technology which, when deployed, is continuously monitored to rapidly detect unforeseen safety issues which are efficiently communicated to AV developers so that they can be immediately addressed. Automation needs to be applied to both AVs and the infrastructure to create this responsive closed loop. Further, this framework should include infrastructure support for wireless (cellular) communications to support CDA, enabling the AV developer community to implement it as they see fit and to enable new approaches to Vulnerable Road User (VRU) safety, first responder safety, safe navigation through temporary detours such as construction zones and to any other enhancements that are enabled by communications.

The safety assurance framework conceptualized by the UL 4600 standard provides a feasible model for AV developers to demonstrate that their technology maintains public safety without being overly prescriptive. Each AV developer can choose how to develop its own safety assurance case, using some combination of the either Design and Development or Test and Validation methods, as described in the IEEE P2846 document currently being developed, outlined in Table 1. Safety assurance case example methods (this list is likely not exhaustive).

Table 1. Safety assurance case example methods

Design and Development Methods	Test and Validation Methods
Systematic Process (e.g., ISO 26262, SOTIF)	System-Level Testing:
Safety Principles (e.g., SAE J3206)	Simulation Testing
Safe by Design Architectures (e.g., SAE J3131)	Closed Course Testing
Robustness Design	Public Road Testing
Formal Methods	Subsystem-Level Testing:
	Software Testing
	Hardware Testing
	MiL/SiL/HiL

For the Test and Validation methods, there are four (4) key components:

1. Test methods: How testing is conducted, including whether the testing is at the system or subsystem level;
2. Operational Safety Assessment (OSA) Metrics: What is measured when testing;
3. Evaluation Methodology(ies): How to use OSA metrics to make an assessment of operational safety;
4. Evaluation Criteria: What level of operational safety is required.

The various types of testing are shown in Table 1. Safety assurance case example methods. System testing takes place either in simulation, on closed courses, or on public roads. Subsystem testing is testing the core elements described by NHTSA (sensing, perception, planning, and control) in software, hardware, or a combination in model-in-the-loop (MiL), software-in-the-loop (SiL), or hardware-in-the-loop plus the possibility of other ADS components. While NHTSA may not want to require it, the usage of the “V Model” of system development is a useful paradigm (see Figure 1 V-model). AV developers are likely to use a combination of test methods, with an

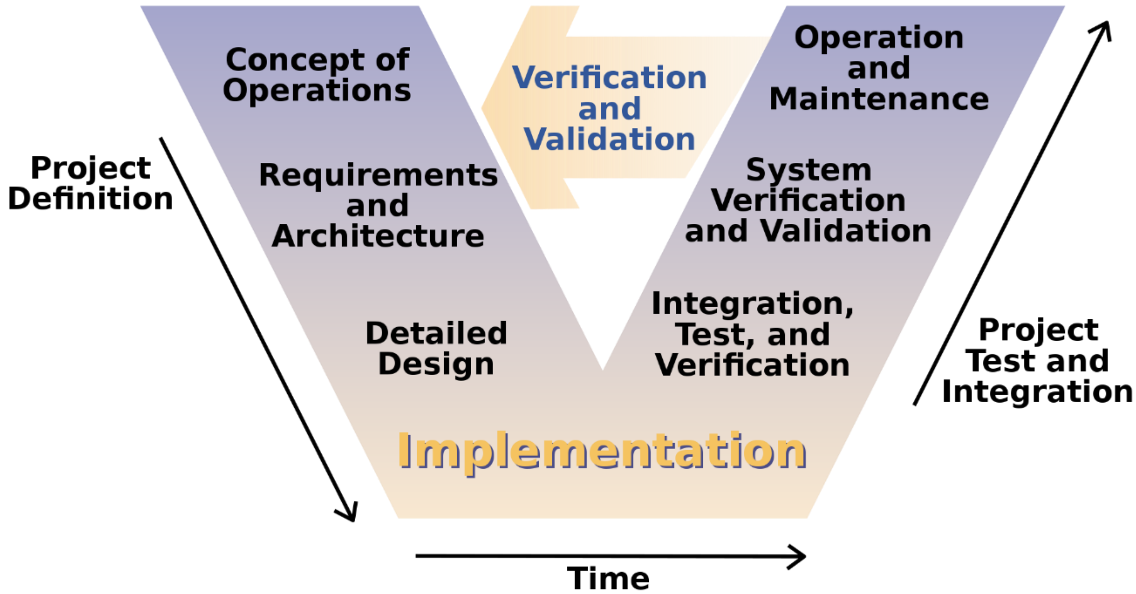

Figure 1 V-model

Source: Public Domain Image from

https://commons.wikimedia.org/wiki/File:Systems_Engineering_Process_II.svg

emphasis on simulation and MiL/SiL/HiL testing due to faster, cheaper testing that these types allow. However, at the system level, closed course and public road testing each have advantages (and disadvantages), and developers are likely to use combinations of them iteratively, starting with simulation testing before moving to closed course and then public road testing, and then as real-world challenges and failures occur, returning to simulation for more thorough examination.

The IAM agrees with NHTSA that a key to the proposed framework is the establishment of OSA metrics that will drive the development of effective testing, inform the specification of standards and regulation, and enable the continuous, automated assessment of operational safety from both the vehicle and infrastructure perspectives. The IAM has pioneered the specification of OSA metrics that can be used from both vehicle and infrastructure perspectives, but has focused on an implementation of metrics measurement from the latter. Our research is focused on how to measure these OSA metrics automatically and cost effectively. Results to date suggest that cost-effective infrastructure deployment is possible and thus we are developing guidelines for deployment at scale possible over the next 3-5 years. Our research contemplates the re-utilization of existing infrastructure such as mono cameras, where possible and on minimalist implementations that provide robust safety assessment.

[Wishart *et al.*, 2020] provides a comprehensive set of OSA metrics following an extensive literature review. The objective was to develop a set of metrics for both human-driven and AVs that includes existing, adapted, and novel metrics. In a follow-up paper [Elli *et al.*, 2021], the IAM has proposed a taxonomy for OSA metrics that incorporates the suggested taxonomy from NHTSA, namely sensing, perception, planning, and control, into a larger framework. [Altekar *et al.*, 2021] provides a discussion of various data capture systems, and the sensor modalities of which the systems are comprised. [Lu *et al.*, 2021] describes the artificial intelligence (AI)- and computer vision-based algorithm that uses the data from the data capture systems to detect and track vehicles in the vicinity of the system, with the ultimate purpose of determining the metrics measurements. The IAM work is also a component of an Information Report being developed by the SAE Verification and Validation (V&V) Task Force under the On-Road Automated Driving (ORAD) Committee [ORAD Committee].

The expanded taxonomy introduced here is shown in Figure 2. The highest taxonomic rank in the proposed taxonomy hierarchy consists of three types that are based, essentially, on the data source, which includes the level of access required of ADS data. This access to proprietary data could be challenging, depending on the implementation of the operational safety metric; it should be noted that "lighter" metrics require more cooperation with the AV developer. The three types are:

1. Black Box Metric: A metric that allows measurement of data that can be obtained without requiring any access to ADS data. This could be from an on-board or off-board source. ADS data may enhance the accuracy and precision of the measurement(s).
2. Grey Box Metric: A metric that allows measurement of data that can only be obtained with limited access to ADS data.
3. White Box Metric: A metric that allows measurement of data that can only be obtained with significant access to ADS data.

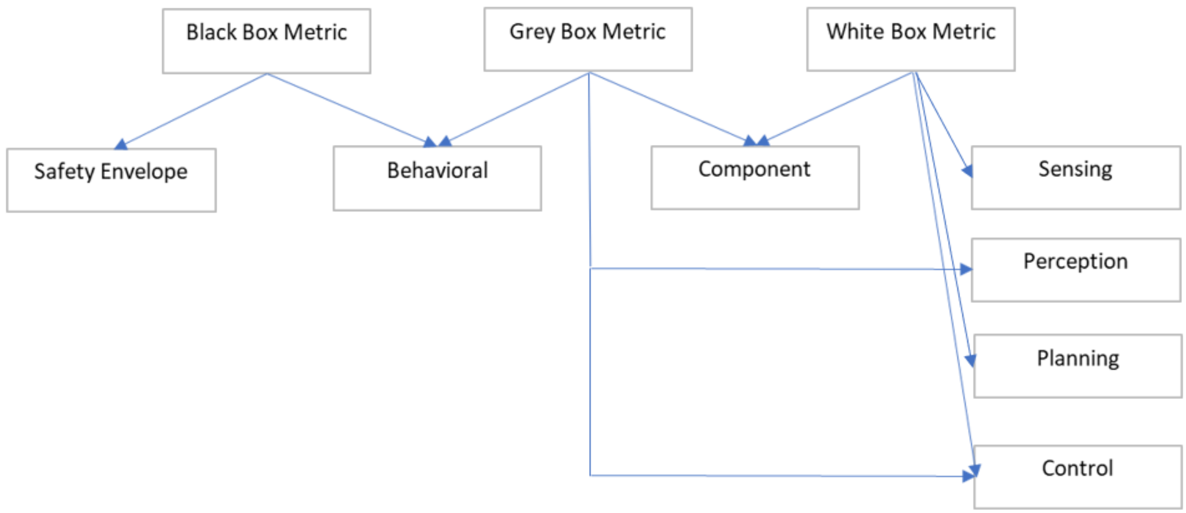

Figure 2. Operational safety metrics taxonomy proposed by the IAM

The second rank in the taxonomic hierarchy is the classification taxonomy, which consists of the following (note the inclusion of the four categories proposed by NHTSA):

1. Safety Envelope Metric: A metric that allows for measurement of the subject vehicle's maintenance of a safe boundary around itself. This includes situations that may not be within the subject vehicle's control.
2. Behavioral Metric: A metric that allows for measurement of an improper behavior of the subject vehicle.
3. Component Metric: A metric that allows for measurement of the proper function of ADS components.
4. Sensing Metric: A metric that allows for measurement of the ability of the ADS sensors to receive adequate information from the AV environment.
5. Perception Metric: A metric that allows for measurement of the ability of the ADS to interpret information about the AV environment obtained by the ADS sensors.

6. Planning Metric: A metric that allows for measurement of the ability of the ADS to plan an appropriate route through the AV environment.
7. Control Metric: A metric that allows for measurement of the ability of the AV to execute the planned route devised by the ADS.

The OSA metrics currently being considered for inclusion in the SAE J3237 Information Report from the SAE ORAD Committee and V&V Task Force include examples from each of the seven classification types, with the intention that future documents from the SAE V&V Task Force will employ select metrics in safety assurance framework development.

The OSA metrics are foundational to assessing operational safety, but by themselves are insufficient. The IAM is currently developing an evaluation methodology that will incorporate the OSA metrics and allow for an assessment of the operational safety performance of an AV as it navigates a given scenario, although this work is in its infancy. It is expected that further collaboration will occur with the SAE ORAD Committee and V&V Task Force in development of this and other evaluation methodologies that will employ the OSA metrics.

Finally, the evaluation criteria pose a difficult issue that the IAM believes requires the input of a variety of stakeholders, such as government agencies, academia, the AV industry, and the general public. It is conceivable that there will be different criteria for different stages of AV development, such as moving from closed course testing to public road testing or transitioning to commercialization. The IAM does not have a position on this issue at this time but would welcome the opportunity to join an effort to establish these evaluation criteria.

Question 2. *In consideration of optimum use of NHTSA's resources, on which aspects of a manufacturer's comprehensive demonstration of the safety of its ADS should the Agency place a priority and focus its monitoring and safety oversight efforts and why?*

The IAM suggests that NHTSA establish the safety assurance framework as described in the response to Question 1 that allows AV developers to demonstrate the safety of their AVs in a flexible yet comprehensive manner. It is critical to regulatory agencies and infrastructure implementers that thorough and compelling AV safety assurance cases be assembled for these vehicles to operate on public roads.

The IAM proposes that the suggested technical focus areas for the proposed ADS framework (sensing, perception, planning and control) be collapsed into three by viewing sensing as simply an enabling technology for perception and treating it as a sub-component of perception. It should be noted that this does not materially change the proposed OSA metrics taxonomy presented in Figure 2. Operational safety metrics taxonomy proposed by the IAM.

Vehicle safety assurance, perception and planning present considerable challenges. Perception systems must overcome imperfect sensor inputs as well as algorithms that are difficult to implement, to produce highly reliable semantic and kinematic situation assessment. Failure to do so can have deadly consequences. In the case of planning, especially for corner-case situations, it requires trustworthy common-sense reasoning which is still very much a nascent research domain. Control is a better understood domain, at least for normal circumstances. Where control is likely to be problematic from a safety perspective is during corner-case scenarios that can be restricted from ODDs until safe operation has been robustly demonstrated.

Precisely understanding the limitations of perception, planning and control systems and defining the ODDs they are capable of effectively operating in should be a priority. In particular, research needs to be conducted into developing standard system test methodologies that accurately predict the performance of these systems in the real world.

It can be argued that perception, planning and control have advanced to the point where ADS can be deployed in certain real-world ODDs, as evidenced by the success of IAM member Mobileye and others. Effective automated monitoring should to be established in concert with these deployments. The feedback this monitoring can provide will minimize the impact of scenarios for which an AV has difficulty navigating. Monitoring can be best conducted from the infrastructure given that it must be capable of observing and correctly assessing the impact AVs have on the entire local traffic flow and across the infrastructure, something that will be impossible to achieve from the ego-car.

Further, effective communications mechanisms, standards and policy need to be established for the rapid communication of observed safety violations to AV developers, regulatory agencies and infrastructure operators so that dangerous activity can be halted and that underlying causes can be dealt with efficiently and effectively. Trustworthiness mechanisms for how AV developers will correct safety issues across their deployed vehicles also need to be developed.

The resultant early detection of safety issues and rapid correction of them is likely to be one of the key advances in transportation safety enabled by automation. However, care must be taken by regulatory agencies to not allow these mechanisms to become a crutch for AV developers. They must maintain rigorous safety assurance procedures that result in fundamentally safe vehicles before they get deployed.

Question 3. *How would your conception of such a framework ensure that manufacturers assess and assure each core element of safety effectively?*

Other than to emphasize how critical rigorous safety assessment and assurance is by AV developers prior to real world deployment, the IAM leaves responses to this question up to the other sectors of the transportation community better positioned to provide them. As described in Table 1. Safety assurance case example methods, there are a variety of methods that can be used to build the safety assurance case for an AV.

Question 4. *How would your framework assist NHTSA in engaging with ADS development in a manner that helps address safety, but without unnecessarily hampering innovation?*

The flexibility and non-prescriptive nature of the proposed safety assurance framework means that innovation would not be hampered through its implementation. Further, automated monitoring will close the loop with ADS developers, enabling rapid detection of operational safety issues, allowing them to be addressed early and often, speeding up the maturation of ADS technology and will help maintain operational safety levels over the long term by rapidly dealing with new safety challenges as they arise due to unanticipated issues associated with the introduction of new ADS designs, S/W updates, infrastructure upgrades, etc.

IAM research suggests that low-cost infrastructure-based monitoring is potentially realizable by repurposing existing deployed technology such as traffic monitoring cameras and by prudently implementing it only where it provides non-redundant, informative insight into vehicle and traffic behavior. Monitoring may only need to be implemented at a representative sample of points of interests (intersections, merge points, etc.) across an infrastructure. This real-time monitoring can be effectively augmented by video post processing in which the troves of video from existing traffic monitoring networks is stored and analyzed, on an as needed basis, using efficient AI approaches that are emerging from the AI research community (eg., https://vaas.csail.mit.edu/docs/introduction.html). Such analysis allows an understanding of safety issues detected across representative samples of points of interest to be effectively amplified. We suggest that NHTSA comprehend the fundamental role of safety monitoring in the proposed safety framework and actively promote the broad implementation of it.

Question 5. *How could the Agency best assess whether each manufacturer had adequately demonstrated the extent of its ADS' ability to meet each prioritized element of safety?*

The ability of NHTSA to assess the demonstration of safety by an AV manufacturer will depend on the elements of the safety assurance case. For example, when employing one of the Design and Development methods listed in Table 1. Safety assurance case example methods, NHTSA could assess the level of adherence to a recognized standard by the AV developer. When employing one of the Test and Validation methods, NHTSA can assess each of the four elements (test methods, OSA metrics, evaluation methodologies, and evaluation criteria) to determine if the desired level of safety has been demonstrated.

Question 6. *Do you agree or disagree with the core elements (i.e., "sensing," "perception," "planning" and "control") described in this notice? Please explain why.*

The suggested technical focus areas for the proposed ADS framework (sensing, perception, planning and control) can be collapsed into three by viewing sensing as simply an enabling technology for perception and treating it as a sub-component of perception.

The IAM also believes that a system-level perspective must also be incorporated into the safety assurance framework. The infrastructure monitoring and Black Box (and Grey Box) metrics could be useful system-level components of the framework.

Question 7. *Can you suggest any other core element(s) that NHTSA should consider in developing a safety framework for ADS? Please provide the basis of your suggestion.*

The safety framework should also comprehend enhancements and automation in the infrastructure:

1. Enhancement of roadway physical attributes such as signage and road markings so that they are optimized for AVs and remove any barriers that are likely to be problematic.
2. Establishment of an operational safety monitoring network at a representative set of point of interest across the infrastructure such as intersections, merge points, pedestrian

walkways, etc., that allows ADS operational safety issues to be rapidly identified and addressed.

3. Provision of low-latency, dependable wireless connectivity to enable V2I (as well as CDA), first responder coordination, construction zone management, VRU safety, roadway usage efficiency optimization, etc.

Question 8. *At this early point in the development of ADS, how should NHTSA determine whether regulation is actually needed versus theoretically desirable? Can it be done effectively at this early stage and would it yield a safety outcome outweighing the associated risk of delaying or distorting paths of technological development in ways that might result in forgone safety benefits and/or increased costs?*

As NHTSA points out in the ANPRM, no fully automated vehicles are yet available on the commercial market and ADS design is still fluid. Regulatory efforts should proceed with this reality in mind.

The development of affordable automated monitoring should be deployed to close the loop with AV developers operating their ADS technology in ODDs appropriate for their designs. The resultant closed-loop collaboration will allow operational safety issues to be addressed and mitigated rapidly and the true state of ADS maturity to be ascertained. As ADS deployment stabilizes and matures, effective regulation will be possible.

Question 9. *If NHTSA were to develop standards before an ADS-equipped vehicle or an ADS that the Agency could test is widely available, how could NHTSA validate the appropriateness* *of its standards? How would such a standard impact future ADS development and design? How would such standards be consistent with NHTSA's legal obligations?*

A deployment readiness methodology and associated testing standards need to be developed. The IAM's efforts to specify the OSA metrics and assessment methodology will help establish the basis required to address this need.

Question 10. *Which safety standards would be considered the most effective as improving safety and consumer confidence and should therefore be given priority over other possible standards? What about other administrative mechanisms available to NHTSA?*

In the short-term, NHTSA should expand automated ADS safety monitoring and the specification of communication and collaboration standards that enable the establishment of a quick reaction closed loop between ADS AV developers and infrastructure operators. NHTSA can also consider some of the standards listed in Table 1. Safety assurance case example methods, IEEE P2846, and other standards from the SAE ORAD Committee.

Question 11. *What rule-based and statistical methodologies are best suited for assessing the extent to which an ADS meets the core functions of ADS safety performance? Please explain the basis for your answers. Rule-based assessment involves the definition of a comprehensive set of rules that define precisely what it means to function safely, and which vehicles can be empirically tested against. Statistical approaches track the performance of vehicles over millions of miles of real-world operation and calculate their probability of safe operation as an extrapolation of their observed frequency of safety violations. If there are other types of methodologies that would be suitable, please identify and discuss them. Please explain the* *basis for your answers.*

The IAM is developing an approach to the monitoring of ADS operational safety from the infrastructure that deploys a comprehensive list of rule-based ADS operational safety metrics along with statistical elements for some of the parameters and thresholds involved. The IAM is conducting research on Mobileye's Responsivity Sensitive Safety concept, which is the basis for several of our measures. We are further developing an evaluation methodology for the translation of measurement results into safety assessments of individual vehicles and traffic. The developed set of metrics allow significant operational safety violations to be rapidly detected and addressed. As data are collected over time, statistical analysis will also be improved, helping to evaluate the maturity of ADS designs.

Question 12. *What types and quanta of evidence would be necessary for reliable demonstrations of the level of performance achieved for the core elements of ADS safety performance?*

Feedback is required for how an ADS performs in its intended ODD. A combination of rigorous AV safety assessment, deployment readiness testing, and real-world monitoring and rapid safety violation mitigation can allow the collection of this data with minimal risk.

Question 13. *What types and amount of argumentation would be necessary for reliable and persuasive demonstrations of the level of performance achieved for the core functions of ADS safety performance?*

See our answers to questions 1 and 12.

ANPRM Question About NHTSA Research

Question 14. *What additional research would best support the creation of a safety framework? In what sequence should the additional research be conducted and why? What tools are necessary to perform such research?*

The IAM, given our infrastructure focus, suggests the following areas for expanded research funding:

- Realizable, affordable automated monitoring needs to be established that can allow safety violations to be rapidly detected and mitigated. Such systems are required throughout the age of ADS deployment, allowing unintended consequences and unanticipated safety issues to be rapidly detected and effectively mitigated, significantly adding to ADS safety.
- The value of cellular communications to automated mobility needs to be established in the real world, clearly establishing what forms of V2X and CDA positively impact safety in significant ways and are economically viable, trustworthy and secure.
- The four elements of the Test and Validation methods (see answer to question 1) need to be established and validated. For the test methods, there are outstanding unknowns such as how to prove and quantify fidelity of simulation and of closed course equipment. It would also be in the public interest for an open source scenario library to be established for research and validation purposes. The development of OSA evaluation methodologies such as that currently being developed by the IAM (that will be a component of future SAE ORAD Committee and V&V Task Force documents) could use support from NHTSA.

- NHTSA could drive research to establish the evaluation criteria necessary to provide clarity on when AVs have reached an agreed-upon level of operational safety in real-world ODDs.

Questions About Administrative Mechanisms and Questions About Statutory Authority

The IAM is a research organization focused on providing guidance to the state of AZ on how best to enable the safe introduction of ADS. To date, we have primarily focused on the role of the infrastructure. In the future, we intend to help with the translation of this technical guidance into policy and administration but have nothing substantive to add to this discussion now.

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