Velodyne Lidar®

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February 28, 2020

Docket Management Facility
U.S. Department of Transportation
1200 New Jersey Avenue SE
West Building Ground Floor, Room W12-140
Washington, DC 20590-0001

Re: Notice and Request for Comments on Advanced Driver Assistance Systems Draft Research Test Procedures, Docket No. NHTSA-2019-0102, 84 Fed. Reg. 64405

On behalf of Velodyne Lidar, I am pleased to submit these comments regarding the National Highway Traffic Safety Administration's ("NHTSA") Request for Comments on the Advanced Driver Assistance Systems ("ADAS") Draft Research Test Procedures published in the Federal Register on November 21, 2019.[1] Velodyne supports NHTSA's efforts to develop research test procedures to objectively and practically assess the performance of certain types of ADAS available to consumers. These vehicle systems present a great opportunity to increase driving safety and reduce the number of roadway deaths and injuries while saving potentially billions of dollars. Indeed, the systems are already having a positive effect. In the current form, however, the NHTSA draft research test procedures could benefit from certain improvements that would further enhance the safety gains of ADAS as these vehicle systems become increasingly widespread in the marketplace.

Accordingly, Velodyne respectfully submits for your consideration these comments, which apply more generally to the nine draft research test procedures and which highlight what we believe could be the main improvements on NHTSA's proposed approach to testing the performance of ADAS. We have also attached to this letter an Appendix that identifies the specific sections of the nine draft test procedures to which our comments apply.[2]

The following comments focus in particular on two aspects of NHTSA's proposed test procedures. First, the ADAS draft research test procedures assess vehicle performance only in a

[1] U.S. Dep't of Transp., Nat'l Highway Traffic Safety Admin., Advanced Driver Assistance Systems Draft Research Test Procedures, Request for Comments, Docket No. NHTSA-2019-0102 (Nov. 21, 2019), https://www.govinfo.gov/content/pkg/FR-2019-11-21/pdf/2019-25217.pdf; *see also* U.S. Dep't of Transp., Nat'l Highway Traffic Safety Admin., Advanced Driver Assistance Systems Draft Research Test Procedures, Request for Comments; Extension of Comment Period, Docket No. NHTSA-2019-0102 (Jan. 22, 2020), https://www.govinfo.gov/content/pkg/FR-2020-01-22/pdf/2020-00938.pdf (extending comment period until March 6, 2020).
[2] *See* Appendix A.

sanitized test-track environment using strict parameters rather than in the real-world conditions that drivers and ADAS are likely to encounter on the road. Second, the draft research test procedures continue an industry trend of creating new ADAS acronyms and functions that may be confusing to consumers and thus may diminish the safety gains of these vehicle systems. After identifying and explaining these aspects of the procedures, the comments conclude with a discussion of a newly proposed five-diamond rating system for ADAS, developed with Velodyne's input, which offers an alternative approach to assessing vehicle system performance in an effort to provide a beneficial level of clarity for industry and consumers.

I. **The ADAS Draft Research Test Procedures Can Be Improved by Capturing Real-World Driving Conditions**

The ADAS draft research test procedures uniformly assess performance based on how the vehicle performs at a testing facility within strictly defined parameters that do not capture the broad range of scenarios commonly encountered in real-world driving. More specifically, the draft test procedures assess performance based on vehicle testing during good weather conditions on a road surface that is dry, straight, and flat, with no irregularities, undulations, and/or cracks, and at speed conditions that are conservatively low (e.g., between 10 and 25 mph).[3] According to the draft test procedures, moreover, vehicles are to be assessed during daylight hours only, with good atmospheric visibility (an absence of fog and the ability to see clearly for more than 3 miles), but not during very low sun angle conditions (where the sun is oriented 15 degrees or less from horizontal and potential camera "washout" or system inoperability could result).[4] And some of the tests must also be conducted such that there are no overhead signs, bridges, or other significant structures over, or near, the testing site, and no vehicles, obstructions, or stationary objects within one lane width of either side of the vehicle path.[5]

Certainly, it is challenging to develop test guidelines that represent a real-world environment while also designing in uniformity and repeatability. Although we recognize that comparing vehicle performance requires testing scenarios and conditions to be regulated at levels of precise granularity, NHTSA should nonetheless consider incorporating into the ADAS draft research test procedures real-world conditions that the current draft testing protocols are not designed to capture (or perhaps even designed not to capture). These conditions could include

[3] *See, e.g.*, U.S. Dep't of Transp., Nat'l Highway Traffic Safety Admin., Blind Spot Detection System Confirmation Test § 4, at 5–6 (Working Draft) (June 2019) ("BSD Test"); U.S. Dep't of Transp., Nat'l Highway Traffic Safety Admin., Pedestrian Automatic Emergency Brake System Confirmation Test § 4, at 5–6 (Working Draft) (Sept. 2019); *see also id.* § 9.2.5.1, at 25.

[4] *See, e.g.*, U.S. Dep't of Transp., Nat'l Highway Traffic Safety Admin., Blind Spot Intervention System Confirmation Test § 4, at 5–6 (Working Draft) (July 2019); U.S. Dep't of Transp., Nat'l Highway Traffic Safety Admin., Opposing Traffic Safety Assist System Confirmation Test § 4, at 4–5 (Working Draft) (Sept. 2019).

[5] *See, e.g.*, U.S. Dep't of Transp., Nat'l Highway Traffic Safety Admin., Test Track Procedures for Heavy-Vehicle Forward Collision Warning and Automatic Emergency Braking Systems § 1.3, at 4–6 (Mar. 2019); BSD Test § 4, at 5–6.

shadows across the roadway, lighting conditions outside of the defined parameters, irregularities in the roadway, increased test vehicle speeds/detection range requirements, curved roadways or irregular route geometries (roundabouts, junctions, merges), roadways with unclear or unmarked lane lines or road edges, and test targets with minimal visual contrast with their surroundings or backgrounds.

These outlying scenarios are more inclusive of real-world driving conditions than those outlined in the ADAS draft research test procedures published in the Request for Comments. By failing to include these scenarios in the draft procedures, NHTSA risks promulgating research procedures for ADAS that do not meaningfully assess how these systems will perform in the real world.

The ADAS draft research test procedures, by excluding real-world testing scenarios, also have the effect of protecting the weaknesses of incumbent sensor modalities. In order to address real-world scenarios and thus be able to improve safety, vehicle sensors must not be confounded by shadows, irregular lane markings, low ambient light, cluttered or low contrast scenes, overhead objects, irregular object shapes, or curved roads. The incumbent systems that utilize cameras as a front-line sensor for object detection and then call on radar to provide objects' distances from the vehicle likely suffer in these real-world conditions. Cameras can be fooled by shadows, are prone to optical illusions, struggle to detect objects that blend with their backgrounds, and lack adequate range in low light conditions. Radar (even next-generation hi-resolution radar) lacks the resolution to distinguish objects at required ranges. Simply adding more cameras and radar will not fix these problems.

By contrast, lidar technology provides crucial advantages over camera and radar in many conditions that would enable vehicles with lidar sensors to address the real-world scenarios outlined above.[6] Unlike radar, lidar provides much higher resolution, enabling accurate object detection, and unlike cameras, lidar provides accurate depth perception, with distance accuracy of a few cm, making it possible to precisely localize the position of the vehicle on the road and detect available free-space for the vehicle to navigate. Lidar also offers 360 degrees horizontal field of view and up to 40 degrees vertical field of view, providing the vehicle the ability to generate dense, high-resolution 3D maps of the environment up to 10–20 times per second, another essential capability for accurately locating the vehicle within its environment and planning its driving path. Moreover, lidar can operate in poor lighting conditions unlike cameras, since lidar is its own light source. These and other perception capabilities of lidar make it a key sensor for ADAS applications in the wide range of real-world scenarios encountered on the road.

[6] To be clear, we are not suggesting that lidar alone should replace all other sensors used in ADAS; rather, we argue only that lidar has unique capabilities that, when combined with the strengths of camera and radar, can further enhance the safety gains of ADAS.

In sum, we submit that NHTSA should consider revising the ADAS draft research test procedures to include real-world conditions as part of the testing parameters. Such a move would set the safety bar at the appropriate level for testing the performance of ADAS. And to the extent the incumbent sensor modalities cannot by themselves perform adequately in the conditions described above, lidar technology can help fill the gaps, with its strengths in accurate object detection and depth perception making up for the weaknesses in camera and radar. Indeed, building vehicle systems with sensor suites that include lidar along with other sensor modalities would enable the strengths of one to cover the weaknesses of the others and thus result in safer and more effective ADAS.

II. The ADAS Draft Research Test Procedures Can Benefit from Avoiding Any Unnecessary ADAS Acronyms and Functions

In addition to including more real-world testing scenarios, the draft research test procedures can also benefit from avoiding where possible an industry trend of creating new and unnecessary ADAS acronyms and functions—a concern that the Department of Transportation recognized when Secretary Chao recently announced that the Department is endorsing a standardized listing of recommended ADAS terminology (based on ADAS functionality) through an initiative entitled "*Clearing the Confusion*," spearheaded by the National Safety Council, the American Automobile Association ("AAA"), Consumer Reports, and J.D. Power.[7] As this initiative reflects, the proliferation of ADAS acronyms and functions, and the varied marketing terminology associated with them, has the potential to reduce the safety gains of ADAS by increasing the risk that consumers may misunderstand and misuse these systems. In a report issued earlier this year highlighting these concerns, AAA identified 20 different names that automakers currently use to describe adaptive cruise control and 19 different names for lane keeping assistance.[8] To address this problem, the report proposes "a set of standardized technology names for use in describing advanced safety systems."[9] The goal of this proposal—one shared by the "*Clearing the Confusion*" initiative—is to foster a dialogue with the automotive industry, safety organizations, and legislators about the need for common naming for ADAS.

Given the concerns associated with the proliferation of ADAS acronyms and functions, and given the Department's recently announced initiative, we submit that NHTSA should consider streamlining the ADAS draft research test procedures to eliminate any unnecessary or duplicative acronyms or functions and thus provide clarity and uniformity in the marketplace.[10] In particular,

[7] *See* Press Release, U.S. Transportation Secretary Elaine L. Chao Announces New Initiatives to Improve Safety on America's Roads (Jan. 15, 2020), https://www.transportation.gov/briefing-room/us-transportation-secretary-elaine-l-chao-announces-new-initiatives-improve-safety.
[8] AAA, *Advanced Driver Assistance Technology Names* 3 (Jan. 2019), https://www.aaa.com/AAA/common/AAR/files/ADAS-Technology-Names-Research-Report.pdf ("AAA Report").
[9] *Id.*
[10] *See generally id.*

NHTSA should consider eliminating several ADAS acronyms and functions in favor of more common existing ones: "Intersection Safety Assist (ISA)" should be replaced by "Forward Collision Warning" or "Forward AEB," "Traffic Jam Assist (TJA)" should be replaced by "Lane Keep Assistance" and "Adaptive Cruise Control" or "Dynamic Driving Assistance," "Blind Spot Detection (BSD)" should be replaced by "Blind Spot Warning," and "Pedestrian Automatic Emergency Brake" should be replaced by "Forward AEB" or a type of "Collision Mitigation." By streamlining the ADAS draft research test procedures in this manner, NHTSA would minimize the potential for consumer confusion or misuse of these systems while advancing the goals of transparency, uniformity, and ultimately safety in the marketplace.

III. A Newly Proposed ADAS Feature Rating System Provides Beneficial Clarity for Industry and Consumers

In light of the potential confusion resulting from the proliferation of ADAS acronyms and functions, SAE International, with input from Velodyne, has made efforts to provide clarity in this rapidly changing and often-perplexing arena. A recently published paper proposes a standardized rating system for assessing the performance characteristics of foundational ADAS features—Lane Keep Assistance ("LKA"), Automatic Emergency Braking ("AEB")/Automatic Emergency Steering ("AES"), Adaptive Cruise Control ("ACC"), and Blind Spot Monitoring ("BSM").[11] The proposed rating system uses diamonds to grade a vehicle system's ADAS feature performance from one to five. Importantly, a one-diamond rating should not be interpreted as a demerit to the system or to the automaker who developed it, but marks achievement of the baseline criteria that must be met for automakers to advertise that a vehicle is equipped with that feature. Whereas the one-diamond rating is designed to capture the minimum performance required to offer that feature, the three-diamond rating is designed to describe the current market-leading level of performance. Thus, the two-diamond rating signals a level of performance that falls between the minimum required capability of that feature and the current state-of-the-art. To date, vehicle systems that perform at the level of one, two, or three diamonds utilize cameras and radar as their main sensor components.

The top two levels of performance for each ADAS feature under consideration have not yet been offered on consumer vehicles. To better understand how the top level of the system is designed, consider this statement from the Boston Consulting Group: "As valuable as ADAS features are in and of themselves, they also serve a vital function as a bridge to autonomous vehicle operation, which will rely on much of the same technology as ADAS."[12] Recognizing that ADAS features are the building blocks of fully driverless vehicle capability, the five diamond ratings are

[11] David Heeren & Mircea Gradu, *An ADAS Feature Rating System: Proposing a New Industry Standard*, Velodyne Lidar (Sept. 2019) (attached as Appendix B).

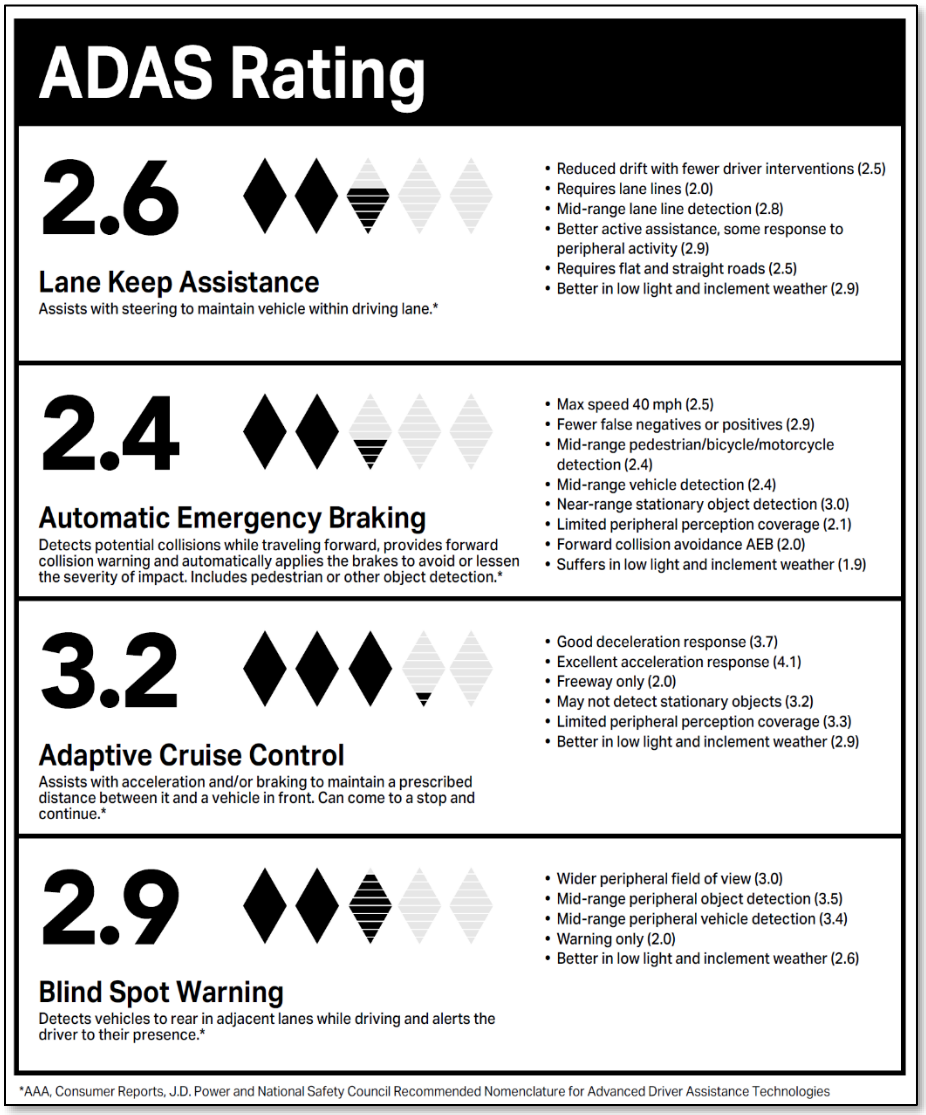
[12] Xavier Mosquet et al., *A Roadmap to Safer Driving Through Advanced Driver Assistance Systems* 19, The Boston Consulting Group for the Motor & Equipment Manufacturers Association (Sept. 29, 2015), http://image-src.bcg.com/Images/MEMA-BCG-A-Roadmap-to-Safer-Driving-Sep-2015_tcm9-63787.pdf.

therefore designed to capture the level of performance that a vehicle system must achieve to reach Level 4 automation, as described by SAE. However, an important caveat applies when considering this level of performance within the context of ADAS: because the vehicle is not truly autonomous, the driver is still fully responsible for monitoring the vehicle's environment and maintaining its safe operation. As a result, the proposed rating system encourages a responsible transition from ADAS to full autonomy, with incremental advancements toward L4 becoming available and extensively vetted in real-world roadway scenarios as ADAS features.

The four-diamond level within each feature is therefore best understood as being better than any current camera and radar-based vehicle system capabilities, but not yet at the level that would be required for that feature to function as it will need to in fully autonomous vehicles. Four- and five-diamond level performance is not attainable without the integration of lidar sensors as a key perception component.

This five-diamond rating system for ADAS features presents new opportunities for conveying vehicles' true capabilities to consumers in a clear and straightforward manner. For example, the ADAS ratings could be included on new-car stickers like the following sticker that NHTSA developed for passive safety system ratings:

A key difference between this NHTSA sticker and a five-diamond sticker, however, is that the five-diamond sticker would present each ADAS feature rating as the average of the vehicle's different performance levels across the feature's criteria. As the following draft sample sticker shows, each ADAS feature rating provides a detailed breakdown of different performance criteria and an individual score for the criteria to explain the basis for the overall ADAS feature rating:



Such a sticker reflecting the five-diamond rating system would recognize the wide range of performance capabilities within each ADAS feature and would communicate these capabilities to consumers in a way that would greatly improve consumer understanding, increase vehicle safety, and ultimately save lives.

In sum, although still in its initial stage of development, the five-diamond rating system seeks to establish a common method for understanding and comparing ADAS performance, thereby delivering a beneficial level of clarity for industry and consumers. Velodyne looks forward to engaging in further discussions with NHTSA about the diamond rating system.

* * *

We appreciate the opportunity to provide comments on NHTSA's ADAS Draft Research Test Procedures. These comments represent only the beginning of Velodyne's engagement with NHTSA and other stakeholders on these important issues affecting the automotive industry and consumers around the world. Should you have any questions regarding any of the comments above or the Appendixes, please contact me at (248) 464-3402 or MGradu@velodyne.com.

Sincerely,

Dr. Mircea Gradu
Senior Vice President Product and Quality
Velodyne Lidar

APPENDIX A

The following chart identifies the sections of the ADAS Draft Research Test Procedures that outline procedures that do not reflect real-world driving conditions and thus would benefit from revisions.

Active Parking Assist (APA)	Blind Spot Detection (BSD)	Blind Spot Intervention (BSI)
Section 4.1 provides that tests shall be performed using a dry, uniform, smooth, level, solid-paved test surface. Surfaces with irregularities, such as dips and large cracks, are unsuitable, as they may confound the test results. **Section 4.2** provides that the lines used to delineate the approach lane and parking spaces shall be considered in "very good condition." **Section 4.4.2** provides that tests should not be performed during periods of inclement weather. This includes, but is not limited to, rain, snow, hail, fog, smoke, or ash. **Section 4.4.3** provides that, unless otherwise specified, the tests shall be conducted during daylight hours with good atmospheric visibility defined as an absence of fog and the ability to see clearly for more than 3 miles (4.8 km). Tests shall not be conducted with the vehicle oriented into the sun during very low sun angle conditions, where the sun is oriented 15 degrees or less from horizontal and potential camera "washout" or system inoperability could result.	**Section 4.1** provides that, unless specified otherwise, the road test surface shall be dry (without visible moisture on the surface), straight, and flat, with a consistent slope between level and one percent. The road surface shall be constructed from asphalt or concrete and shall be free of irregularities, undulations, and/or cracks that could cause the SV to pitch excessively. **Section 4.2** provides that all lane lines shall be considered in "very good condition." **Section 4.4.3** provides that tests should not be performed during periods of inclement weather. This includes, but is not limited to, rain, snow, hail, fog, smoke, or ash. **Section 4.4.4.** provides that the tests shall be conducted during daylight hours with good atmospheric visibility defined as an absence of fog and the ability to see clearly for more than 3 miles (4.8 km). Tests shall not be conducted with the vehicle oriented into the sun during very low sun angle conditions, where the sun is oriented 15 degrees or less from horizontal and potential camera "washout" or system inoperability could result. **Section 4.4.4** also provides that all tests shall be conducted such that there are no overhead signs, bridges, or other significant structures	**Section 4.1** provides that the road test surface shall be dry (without visible moisture on the surface), straight, and flat, with a consistent slope between level and one percent. The road surface shall be constructed from asphalt or concrete and shall be free of irregularities, undulations, and/or cracks that could cause the SV to pitch excessively. The surface shall be free of excessive tire skid marks, pavement seam sealer, and/or other high-contrast surface markings that could potentially confound lane line identification and/or tracking. **Section 4.2** provides that all lane lines shall be considered in "very good condition." **Section 4.4.3** provides that tests should not be performed during periods of inclement weather. This includes, but is not limited to, rain, snow, hail, fog, smoke, or ash. **Section 4.4.4** provides that the tests shall be conducted during daylight hours with good atmospheric visibility defined as an absence of fog and the ability to see clearly for more than 3 miles (4.8 km). Tests shall not be conducted with the vehicle oriented into the sun during very low sun angle conditions, where the sun is oriented 15 degrees or less from horizontal and potential camera "washout" or system inoperability could result.

	over, or near, the testing site. Except for the POV, each trial shall be conducted with no vehicles, obstructions, or stationary objects within one lane width of either side of the SV path.	
Intersection Safety Assist (ISA)	**Opposing Traffic Safety Assist (OTSA)**	**Pedestrian Automatic Emergency Braking (PAEB)**
Section 4.1 provides that the road test surface shall be dry (without visible moisture on the surface), straight, and flat, with a consistent slope between level and one percent. The road surface shall be constructed from asphalt or concrete and shall be free of irregularities, undulations, and/or cracks that could cause the SV to pitch excessively. The surface shall be free of excessive tire skid marks, pavement seam sealer, and/or other high-contrast surface markings that could potentially confound lane line identification and/or tracking. **Section 4.3** provides that all lane lines shall be considered in "very good condition." **Section 4.3.3** provides that tests should not be performed during periods of inclement weather. This includes, but is not limited to, rain, snow, hail, fog, smoke, or ash. **Section 4.3.4.** provides that the tests shall be conducted during daylight hours with good atmospheric visibility defined as an absence of fog and the ability to see clearly	**Section 4.1** provides that the road test surface shall be dry (without visible moisture on the surface), straight, and flat, with a consistent slope between level and one percent. The road surface shall be constructed from asphalt or concrete and shall be free of irregularities, undulations, and/or cracks that could cause the SV to pitch excessively. The surface shall be free of excessive tire skid marks, pavement seam sealer, and/or other high-contrast surface markings that could potentially confound lane line identification and/or tracking. **Section 4.2** provides that all lane lines shall be considered in "very good condition." **Section 4.4.3** provides that tests should not be performed during periods of inclement weather. This includes, but is not limited to, rain, snow, hail, fog, smoke, or ash. **Section 4.4.4.** provides that the tests shall be conducted during daylight hours with good atmospheric visibility defined as an absence of fog and the ability to see clearly for more than 3 miles (4.8 km). Tests shall not be conducted with the vehicle oriented into the sun during very low sun angle conditions, where the sun is	**Section 4.1** provides that, unless specified otherwise, the road test surface shall be dry (without visible moisture on the surface), straight, and flat, with a consistent slope between level and one percent. The road surface shall be constructed from asphalt or concrete and shall be free of irregularities, undulations, and/or cracks that could cause unwanted movement of the SV. **Section 4.1** further provides that each trial shall be conducted with no other vehicles, obstructions, or stationary objects within one lane width of either side of the SV test lane of travel except when explicitly stated. **Section 4.2.3** provides that tests shall not be performed during periods of inclement weather. This includes, but is not limited to, rain, snow, hail, fog, smoke, and/or ash. **Section 4.2.4.** provides that the tests shall be conducted during daylight hours with good atmospheric visibility defined as an absence of fog and the ability to see clearly for more than 3 miles (4.8 km). Tests shall not be conducted with the vehicle oriented into the sun during very low sun angle conditions, where the sun is

for more than 3 miles (4.8 km). Tests shall not be conducted with the vehicle oriented into the sun during very low sun angle conditions, where the sun is oriented 15 degrees or less from horizontal and potential camera "washout" or system inoperability could result.	oriented 15 degrees or less from horizontal and potential camera "washout" or system inoperability could result.	oriented 15 degrees or less from horizontal and potential camera "washout" or system inoperability could result. **Section 4.2.4** further provides that all tests shall be conducted in an area void of overhead signs, bridges, or other significant structures over or near the testing site. Each trial shall be conducted with no vehicles, obstructions, or stationary objects within one lane width of either side of the SV path, unless otherwise specified. Shadows cast by objects other than the SV, test equipment, or the obstructing vehicles shall not be present in the SV lane of travel, or within one lane width of either side of the SV path. **Section 9.2.5.1.C** provides that the SV shall be driven at nominal speeds ranging from 10 mph to 25 mph.
Rear Automatic Braking	**Traffic Jam Assist (TJA)**	**Forward Collision Warning (FCW) & Automatic Emergency Braking (AEB)**
Section 6.2 in Appendix A provides that the test course or proving ground facilities shall have straight, level road sections of length at least 12 m and that road surfaces shall be well-maintained, smooth, and without bumps, creases, or potholes. Testing should be performed in a wide-open area to ensure that the system is detecting the test object and not another object in the vicinity. **Section 10.1 in Appendix A** provides that tests should not be performed during	**Section 3.0** provides that TJA is a driver assistance system capable of automatically controlling the lateral position of the SV within its travel lane while simultaneously and automatically establishing and maintaining a constant longitudinal headway behind the vehicle immediately ahead of it at speeds up to 25 mph. **Section 4.1** provides that the road test surface shall be dry (without visible moisture on the surface), straight, and flat, with a consistent slope between level and one percent. The road	**Section 1.3** provides that the road surface shall be a straight path and the testing surface dry without water delivery. The surface is flat, constructed from asphalt or concrete, and free of bumps, cracks, and potholes that could induce excessive SV pitch motion. With exception to vehicles, test targets, and stationary objects that are called for in test procedures, there are no vehicles, obstructions, or stationary objects within one lane width of 12 feet of either side of the vehicle path.

periods of inclement weather. This includes, but is not limited to, rain, snow, hail, fog, smoke, and/or ash.	surface shall be constructed from asphalt or concrete and shall be free of irregularities, undulations, and/or cracks that could cause the SV to pitch excessively. The surface shall be free of excessive tire skid marks, pavement seam sealer, and/or other high-contrast surface markings that could potentially confound lane line identification and/or tracking. **Section 4.2** provides that all lane lines shall be considered in "very good condition." **Section 4.4.3** provides that tests should not be performed during periods of inclement weather. This includes, but is not limited to, rain, snow, hail, fog, smoke, or ash. **Section 4.4.4** provides that the tests shall be conducted during daylight hours with good atmospheric visibility defined as an absence of fog and the ability to see clearly for more than 3 miles (4.8 km). Tests shall not be conducted with the vehicle oriented into the sun during very low sun angle conditions, where the sun is oriented 15 degrees or less from horizontal and potential camera "washout" or system inoperability could result.	**Section 1.3** further provides that tests are not to be performed during periods of inclement weather. This includes rain, snow, hail, fog, smoke, and/or ash. The tests are to be conducted during daylight hours with good atmospheric visibility, defined as an absence of fog and the ability to see clearly for more than 5 km (3.1 miles). The tests are not to be conducted during very low sun angle conditions (where the sun is oriented 15 degrees or less from horizontal) as camera "washout" or system inoperability may result. **Section 1.3** also states that all tests are to be conducted in an area void of overhead signs, bridges, or other significant structures over the testing site. Each trial is conducted with no unrelated vehicles, obstructions, or stationary objects within one lane width of either side of the SV path. Shadows cast by objects other than the SV, POV, POV test apparatus, POV tow vehicle, or steel trench plate are not present in the SV lane of travel, or within one lane width of either side of the SV path.

APPENDIX B

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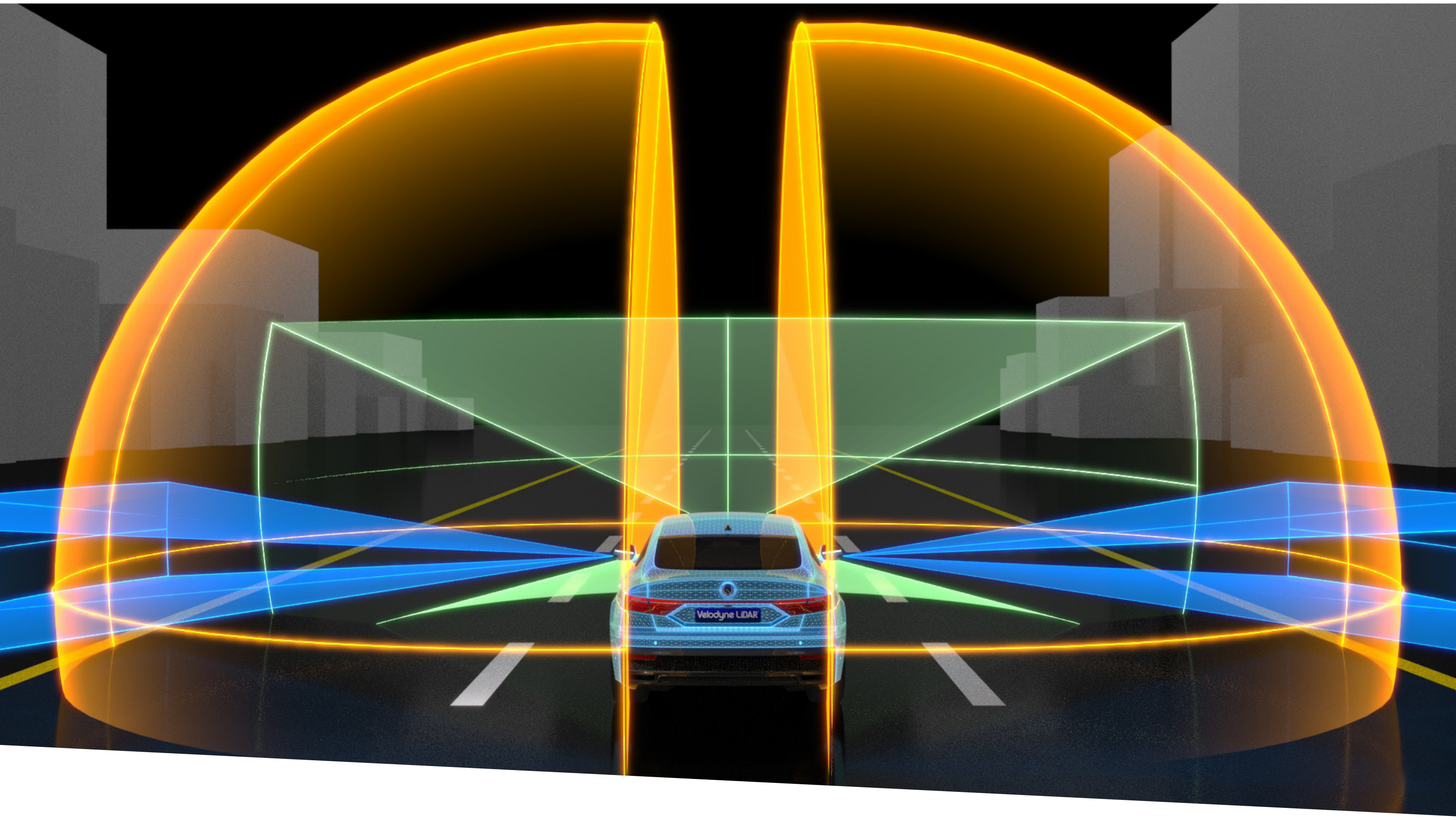

AN ADAS FEATURE RATING SYSTEM: PROPOSING A NEW INDUSTRY STANDARD

White Paper

Sep 2019

A version of this paper has been published as a series by Society of Automotive Engineers (SAE) International

AN ADAS FEATURE RATING SYSTEM: PROPOSING A NEW INDUSTRY STANDARD

ABSTRACT

More than 90% of new vehicles include Advanced Driving Assistance Systems that offer features such as Lane Keep Assist and Adaptive Cruise Control[1]. These ever-improving vehicle systems present a great opportunity to increase driving safety and reduce the number of roadway deaths and injuries. Indeed, they are already having a positive effect. However, the wide variety of features offered in the marketplace can be confusing to consumers, who may not clearly understand their vehicles' true capabilities and limitations, or have an easy way of comparing system performance between vehicle models. This lack of information has the potential to reduce the safety gains of ADAS features by increasing the risk of improper use. To encourage transparency in the marketplace and thus engender the maximum positive effect of ADAS technologies, this paper proposes a five-level rating system, which utilizes diamonds to denote significant milestone achievements in vehicle system performance. The rating charts resulting from this system describe gradients of performance within criteria addressed by certain foundational ADAS features. Presented here in its initial stage of development, this rating system will require continued refinement. We therefore encourage the community of automotive safety organizations to take up the mantle by establishing and performing test protocols for assigning standardized ADAS feature performance ratings. We believe that the result of this effort, a common method for understanding and comparing ADAS performance, promises to deliver a beneficial level of clarity to the industry and consumers.

INTRODUCTION

The technology inside consumer vehicles is developing at a rate the market has never seen. Rapid advancements in sensor, software, and processing components are converging within the automotive sector to unlock intelligent performance capabilities that promise to greatly increase drivers' comfort and safety. Advanced Driving Assistance Systems (ADAS) include features such as Lane Keep Assistance (LKA), Automatic Emergency Braking (AEB), Automatic Emergency Steering (AES), Adaptive Cruise Control (ACC), and Blind Spot Monitoring (BSM), which are already common options, and increasingly come standard, on new vehicles. In 2018, 92.7% of new vehicles sold in the U.S. offered at least one ADAS feature, with the average ADAS package costing consumers about $1,950 [1]. These features are already yielding positive results; for example, one automaker's vehicles equipped with AEB and forward collision warning are reportedly involved in 43% fewer front-to-rear crashes [2]. And the potential benefit of further advancements is astounding. Reducing the number of front-facing crashes by 90% would prevent about 27,000 deaths and $635 billion dollars in total societal harm, annually [3].

However, rapid changes in automotive technology can also be disorienting for consumers. Even more, if marketing materials are misleading or do not align with guidelines for safe operation, drivers might overestimate their vehicle's capabilities. The proliferation of ADAS features and the marketing terminology being attached to them inspired the American Automobile Association (AAA) to recently propose "a set of standardized technology names for use in describing advanced safety systems." For example, AAA identified 20 different names automakers currently utilize to describe features that could all be subsumed under the category of "Adaptive Cruise Control." [1]

Advancing AAA's efforts to generate clarity in this rapidly changing and often perplexing arena, this paper proposes a standardized rating system for assessing the performance characteristics of foundational ADAS features -- LKA, AEB/AES, ACC, and BSM.

The notion that a spectrum of performance levels exists for ADAS features is supported by Euro NCAP's "2025 Roadmap." Importantly, this report also highlights that automakers are introducing new sensors to vehicles in order to improve performance in a broader range of conditions. Discussing AEB features specifically, the report reads, "The performance of an AEB system is dependent on the type and complexity of the sensors used. More and more manufacturers are adding additional sensors and combining multiple sensor types together in 'fusion' to offer the potential to address new and more complex crash scenarios." [4]

This project extends the call, recently articulated in an SAE Edge Research Report, for an increasingly taxonomical approach to understanding differences in sensor technologies utilized in automated and advanced driving systems. The charts that follow represent a draft framework to facilitate an understanding of ADAS feature performance levels that can be shared between component suppliers, automakers, dealerships, and consumers. We hope this project offers an immediate contribution to the field by identifying the key criteria upon which these features can be evaluated.

However, we anticipate the need for further refinement and quantification of particular performance descriptors. For example, the industry will surely demand more precision in defining the difference between roads that are "flat and straight" versus "hilly and curvy." Performance testing parameters should also include a broad range of carefully defined lighting and weather conditions. Also, within the lidar industry, we realize that detection ranges cannot be compared in isolation from other factors, such as object reflectivity and the sensor's field of view. Further, a sensor's placement within the vehicle, for example behind the windshield or in the bumper, has a critical effect on the sensor's practical field of view. Therefore, in testing and attributing ratings to vehicles' ADAS performance, considerations of sensor placement and the system's resulting coverage of the surrounding 3D space will need to be accounted for, beyond the specifications provided by component suppliers.

Beyond performance, we anticipate that future ADAS rating frameworks will address vehicle systems' functional safety achievements, including considerations of their reliability, failure monitoring, and self-diagnosis functions. Further variation between ADAS systems can be described with regards to their relative abilities to self-clean their sensor components, their immunity to cyber threats, and whether they incorporate redundant, overlapping fields of view. Certainly, organizations such as Euro NCAP are experts in developing rigorous and regimented testing protocols and can help strengthen and implement this aspect of the proposed rating system.

Movement towards a standardized framework for understanding vehicle systems' capabilities would have far-reaching effects in the industry. The Boston Consulting Group states:

> Systematizing a rating system for ADAS features and factoring that into overall vehicle ratings would signal recognition of the importance of ADAS features and influence consumer choices. Like Euro NCAP, [market research and rating agencies such as J.D. Power and publications such as Consumer Reports] could require the inclusion of ADAS technologies and features in any vehicle aspiring to their top safety rating. [5]

We build on this vision by advocating that safety ratings should consider not only the presence of certain ADAS features but also their level of performance. Our main goal in proposing a method for systematically rating ADAS features is the very same reason these features are included on vehicles in the first place: to improve roadway safety. With this rating system, automakers will have a better understanding of the performance levels they are working to achieve and will be able to intentionally aim for higher ratings. Marketing practices will gain an added level of transparency and utilize common terminology. Providing consumers access to clear descriptions of what their vehicles can and cannot do will encourage responsible implementation. Finally, this rating system enables consumers to make comparisons across common criteria and promotes competition between automakers to develop and deliver increasingly better-performing ADAS features.

DISSECTING THE DIAMOND RATING SYSTEM

The proposed rating system utilizes diamonds to grade a vehicle system's ADAS feature performance from one to five. Importantly, a one diamond rating should not be interpreted as a demerit to the system or to the automaker who developed it, but marks achievement of the baseline criteria that must be met for automakers to advertise that a vehicle is equipped with that feature. Whereas we designed the one diamond rating to capture the minimum performance required to offer that feature, our three-diamond rating is designed to describe the current market-leading level of performance. Thus, the two-diamond rating signals a level of performance that falls between the minimum required capability of that feature and the current state-of-the-art. To date, vehicle systems that perform at the level of one, two, or three diamonds utilize cameras and radar as their main sensor components.

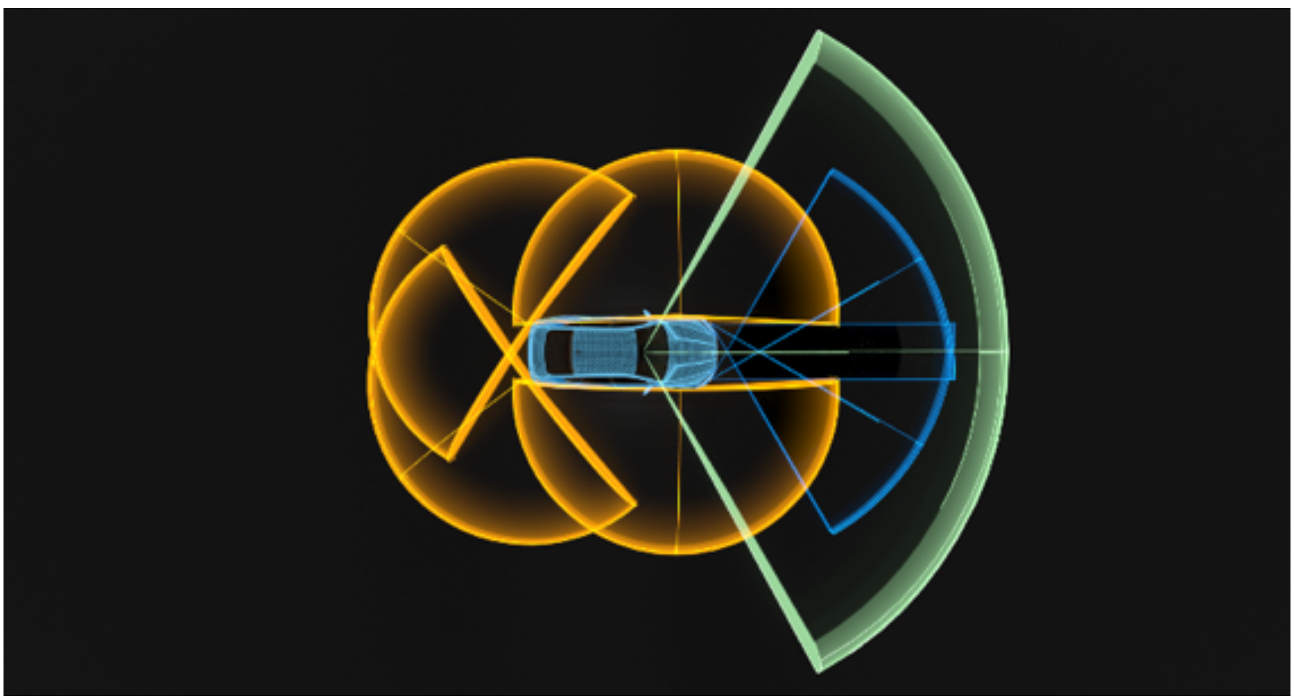

Figure 1. One example of possible lidar sensor coverage to achieve five diamond level ADAS performance (top down view).

The top two levels of performance for each ADAS feature under consideration have not yet been offered on consumer vehicles. To better understand how we designed the top level of our system, consider this statement from the Boston Consulting Group: "As valuable as ADAS features are in and of themselves, they also serve a vital function as a bridge to autonomous vehicle operation, which will rely on much of the same technology as ADAS" [5]. Recognizing that ADAS features are the building blocks of fully driverless vehicle capability, the five diamond ratings in the following charts are therefore designed to capture the level of performance that a vehicle system must achieve to reach Level 4 automation, as described by SAE. [6] However, an important caveat applies when considering this level of performance within the context of ADAS: because the vehicle is not truly autonomous, the driver is still fully responsible for monitoring the vehicle's environment and maintaining its safe operation. As a result, the proposed rating system encourages a responsible transition from ADAS to full autonomy, with incremental advancements towards L4 becoming available and extensively vetted in real world roadway scenarios as ADAS features.

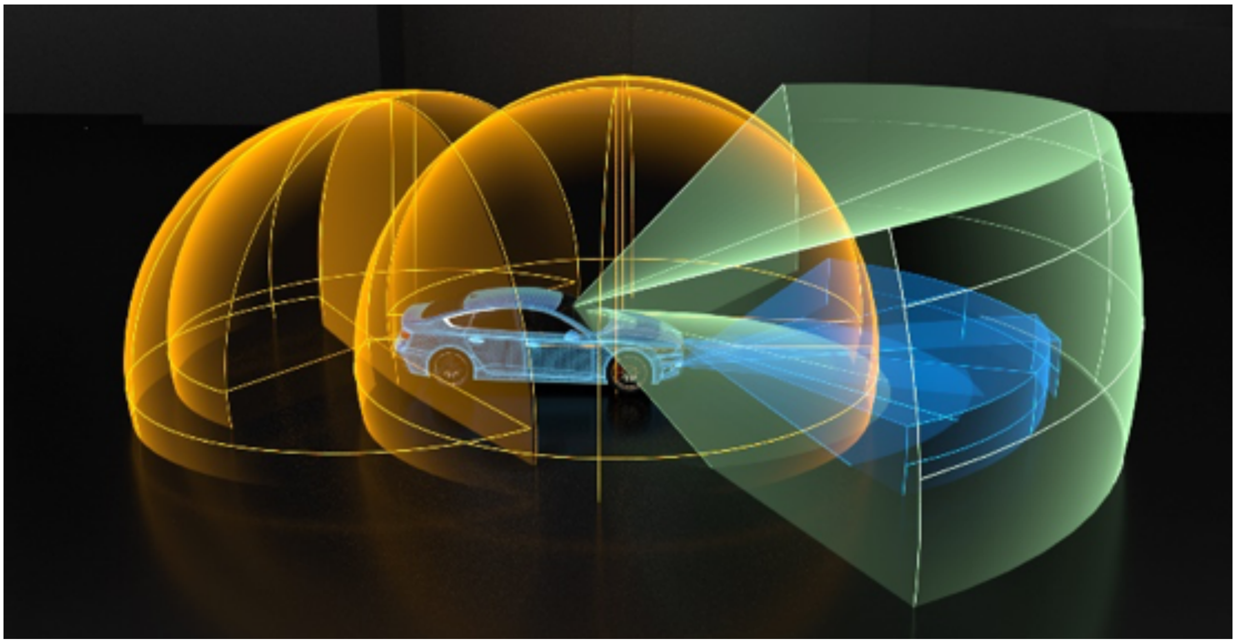

Figure 2. One example of possible lidar sensor coverage to achieve five diamond level ADAS performance (side view).

The four-diamond level within each feature is therefore best understood as being better than any current camera and radar-based vehicle system capabilities, but not yet at the level that would be required for that feature to function as it will need to in fully autonomous vehicles. We believe that four and five diamond level performance is not attainable without the integration of lidar sensors as a key perception component. Figures 1 and 2 illustrate examples of lidar placement that would support five diamond level performance. Before moving to an examination of the performance criteria upon which ADAS features shall be evaluated, it is important to recognize that there will exist a gradient of performance within each diamond level. That is, there will likely be permutations of performance characteristics within any given level that exceed the minimum criteria attributed to that rating but that do not quite reach the next level ahead.

IDENTIFYING THE PERFORMANCE CRITERIA OF EACH FEATURE

Lane Keep Assistance, Automatic Emergency Braking, Automatic Emergency Steering, Adaptive Cruise Control, and Blind Spot Monitoring are the foundational features of Level 2+ ADAS (as well as Level 4+ autonomy). For each of these features, this section will review the minimum performance requirements for vehicle systems to satisfy the baseline definitions proposed by AAA. We will also outline several of the key criteria and the variation of vehicle system performance within these criteria, which creates the framework of our rating system for each feature. For example, for each of the following features, one measure of a system's capability is its Light and Weather Performance, which ranges from suffering in low light or inclement weather at lower levels to performing well in all light and most weather conditions at the four and five diamond levels.

AAA defines Lane Keep Assistance as a feature that "Controls steering to maintain vehicle within driving lane. May prevent vehicle from departing lane or continually center vehicle"[1]. The performance criteria we identify for this feature include Lane Positioning, or the system's ability to keep the vehicle within the lane, which directly correlates with the number of required driver interventions. Whereas lower levels of LKA experience considerable drift within the lane, requiring the driver to frequently take over the steering task, a five diamond rating denotes that the system steers the vehicle along an optimized driving trajectory, which may not always be simply centered within the lane depending on the scenario, and does not require the driver to take the wheel. A second performance indicator within LKA is Lane Line Dependence, which ranges from the requirement of clear lane lines in the lowest level to the ability to navigate roadways without needing to detect lane lines at the five-diamond level. Further, within LKA there is a broad range of performance capability related to Roadway Functionality, with lower rated systems requiring flat and straight roads, and five diamond systems excelling on all types of roadways

Table 1. Proposed guidelines for standardized five diamond rating system for Lane Keep Assistance.

Lane Keep Assistance

Vehicle System Performance Criteria	♦	♦♦	♦♦♦	♦♦♦♦	♦♦♦♦♦
Lane Positioning	Drifts within lane, frequent driver intervention	Reduced drift, fewer driver interventions	Excellent centering. occassional driver interventions	Excellent centering. occassional driver interventions	Optimized driving trajectory, no driver interventions
Lane Line Dependance	Requires clear lane lines	Requires lane lines	Requires lane lines	Requires lane lines	No lane lines required
Lane Line Detection Range	Near-range detection	Mid-range detection	Mid-range detection	Mid-range detection	No lane lines required
Dynamic Driving Inter-vention Capability	Minor late corrections, no response to peripheral activity	Better active assistance, some response to peripheral activity	Excellent active assistance, good response to peripheral activity, Lane Change Assist	Excellent active assistance, good response to peripheral activity, Lane Change Assist	Superior navigation, smooth and comfortable ride, excellent reponse to peripheral activity, Lane Change Assist
Roadway Functionality	Flat and straight roads	Flat and straight roads	Better on curves and hills	Better on curves and hills	Excellent on all roads
Light and Weather Performance	Suffers in low light and inclement weather	Better in low light and inclement weather	Better in low light and inclement weather	Performs well in all light and most weather	Performs well in all light and most weather

Table 2. Proposed guidelines for standardized five diamond rating system for Automatic Emergency Braking and Automatic Emergency Steering.

Automatic Emergency Braking and Automatic Emergency Steering

Vehicle System Performance Criteria	♦	♦♦	♦♦♦	♦♦♦♦	♦♦♦♦♦
Max Speed	10 mph	30 mph	50 mph	65 mph	75 mph
Detection Reliability	Frequent false negatives or positives	Fewer false negatives or positives	Occasional false negatives or positives	Extremely rare false positives or negatives	Extremely rare false positives or negatives
Pedestrian, Bicycle, Motorcycle Detection and Classification Range	Near range detection, no classification	Mid-range detection	Mid-range detection and classification	Mid-range detection and classification	Far-range detection and classification
Vehicle Detection and Classification Range	Near range detection, no classification	Mid-range detection	Mid-range detection and classification	Far-range detection and classification	Far-range detection and classification
Stationary Object Detection and Classification Range	May not detect	May not detect	Near range detection	Mid-range detection and classification	Far-range detection and classification
Peripheral Object Detection and Classification Coverage	No perception coverage	Limited perception coverage	Limited perception coverage	Improved perception coverage	Excellent perception coverage
Dynamic Driving Intervention Capability	AEB for crash mitigation	Forward collision avoidance AEB	Forward collision avoidance with steer and brake control	Forward and side collision avoidance with steer and brake control	Forward and side collision avoidance with steer and brake control
Light and Weather Performance	Suffers in low light and inclement weather	Better in low light and inclement weather	Better in low light and inclement weather	Performs well in all light and most weather	Performs well in all light and most weather

Another key performance gradient related to LKA is Dynamic Driving Intervention Capability, with baseline systems delivering steering corrections that are often late, minor, or uncomfortable. In contrast, five diamond level LKA provides a consistently smooth and comfortable ride. Additionally, higher rated levels of LKA expand on the capabilities described in AAA's baseline definition. Thus, in LKA and several of the other ADAS features under consideration, advanced performance levels build on the baseline capabilities to the extent that they enable additional features. For example, higher levels of Lane Keep Assistance include Dynamic Driving Assistance in the form of Lane Change Assist. Such a result points to the close relationship between many secondary active dynamic driving assistance capabilities that represent the logical maturation of foundational features.

Forward Automatic Emergency Braking and Automatic Emergency Steering offer another example of a close relationship between ADAS features, which we have captured in Table 2. According to AAA, Forward Automatic Emergency Braking "Detects potential collisions while traveling forward and automatically applies brakes to avoid or lessen the severity of impact" [1]. This capability marks the entry point of our rating system for these features. However, higher level systems in this category also display the ability to perceive and respond to potential side impacts while driving forward. Higher levels also avoid crashes with Automatic Emergency Steering, which "Detects potential collision and automatically controls steering to avoid or lessen the severity of impact." Other key performance criteria within these features are related to Detection Reliability, or the rate of false positive and negative readings, and perception coverage, which factors in the system's range and field view.

Table 3 addresses Adaptive Cruise Control, which, according to AAA, "Controls acceleration and/or braking to maintain a prescribed distance between it and a vehicle in front. May be able to come to a stop and continue" [1]. Key performance criteria for this feature include the comfort and responsivity of acceleration and deceleration. Other important capabilities for ACC are detection and classification ranges of moving and stationary objects both in front and peripherally. Finally, ACC features can be compared based on the range of roadways upon which they are able to function, with lower rated systems being limited to freeway settings and higher rated systems operating well on all types of roadways.

Table 4 describes the performance gradient related to Blind Spot Monitoring, which, according to AAA, "Detects vehicles to rear in adjacent lanes while driving and alerts driver to their presence" [1]. Higher level systems build on this capability to actively avoid collisions with vehicles, pedestrians, bicycles, and motorcycles occupying drivers' blind spots. Another logical expansion of this feature in higher levels is Lane Change Assist. These advanced Dynamic Driving Assistance features require not only broad peripheral perception coverage, but also forward-facing perception.

Table 3. Proposed guidelines for standardized five diamond rating system for Adaptive Cruise Control.

Adaptive Cruise Control

Vehicle System Performance Criteria	♦	♦♦	♦♦♦	♦♦♦♦	♦♦♦♦♦
Maintains programmed following distance	Uncomfortable, late deceleration	Improved deceleration response	Good deceleration response	Excellent deceleration response	Excellent deceleration response
Automatic resume after slow/stop	Does not automatically resume	Improved acceleration response	Good acceleration response	Excellent acceleration response	Excellent acceleration response
Roadway Functionality	Freeway only	Freeway only	Freeway/highway	Rural and city streets and freeways/highways	Rural and city streets and freeways/highways
Stationary object detection and classification range	May not detect	May not detect	May not detect	Mid-range detection and classification	Far-range detection and classification
Peripheral object detection and classification coverage	No perception coverage	Limited perception coverage	Limited perception coverage	Good perception and classification coverage	Broad detection and classification coverage
Light and Weather Performance	Suffers in low light and inclement weather	Better in low light and inclement weather	Better in low light and inclement weather	Performs well in all light and most weather	Performs well in all light and most weather

Table 4. Proposed guidelines for standardized five diamond rating system for Blind Spot Monitoring.

Blind Spot Monitoring

Vehicle System Performance Criteria	♦	♦♦	♦♦♦	♦♦♦♦	♦♦♦♦♦
Peripheral field of view	Narrow	Wider	Wider	Broad, 180 degree field of view	Broader than 180 degree field of view
Peripheral vehicle detection and classification coverage	Near range detection	Mid-range detection	Mid-range detection	Mid-range detection and classification	Expansive mid-range detection and classification
Peripheral object detection and classification coverage	May not detect	May not detect	Mid-range detection	Mid-range detection and classification	Expansive mid-range detection and classification
Dynamic driving intervention capability	Warning only	Warning only	Active collision avoidance with vehicle in blindspot	Active avoidance of vehicles, motorcycles, bicycles, and pedestrians	Active avoidance of vehicles, motorcycles, bicycles, and pedestrians; Lane Change Assist
Light and Weather Performance	Suffers in low light and inclement weather	Better in low light and inclement weather	Better in low light and inclement weather	Performs well in all light and most weather	Performs well in all light and most weather

SUMMARY

Rapid developments within driving assistance technologies necessitate unambiguous marketing and communication from automakers and dealerships so that customers understand, in clear terms, what their vehicles can do, under what conditions, and with what limitations. It is no longer enough to simply list ADAS features such as LKA or ACC on the sticker. We also need a shared, consistent method for rating these features. To advance this project beyond the current proposal, a third-party organization will likely need to further refine the performance descriptions and adapt testing protocols to fit these use cases. We are eager to continue the conversation because the potential impact is tremendous. Improving driving safety is a paramount concern within the industry -- and advancing safety requires not only revolutionary technology, but common, transparent standards clearly conveyed to customers to allow responsible implementation.

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DEFINITIONS/ABBREVIATIONS

ACC Adaptive Cruise Control

ADAS Advanced Driving Assistance System

AEB Automatic Emergency Braking

AES Automatic Emergency Steering

BSM Blind Spot Monitoring

LKA Lane Keep Assist

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