PART 5 – ~~AUTOMATED~~ DRIVING AUTOMATION SYSTEM-EQUIPPED VEHICLES

CHAPTER 5A. GENERAL

Section 5A.01 Purpose and Scope

Support:

The purpose of this Chapter is to provide agencies with general considerations for vehicles equipped with driving automation systems as they assess their infrastructure needs, prepare their roadways for ~~automated vehicle (AV)~~driving automation technologies, and to support the safe deployment of automated ~~vehicle~~ driving technology.

This Chapter provides an overview of foundational ~~CAV~~driving automation technology terminology, key principles, considerations for traffic control device selection, and topics for agencies to consider. The MUTCD does not address standardizing several areas that might be important to ~~CAV~~ driving automation technologies such as digital infrastructure, geometric road design, setting maintenance levels for all traffic control devices, and setting minimum condition levels for paving materials.

It is important for early implementers of driving automation system-equipped ~~automated~~ vehicles to understand the ramifications of traffic control devices in a mixed fleet environment and to consider the needs of both human and machine led road users. Partial driving automation technologies are already commercially available in the vehicle fleet and are operating under current infrastructure conditions. The overall effectiveness of the driving automation technology is impacted by the uniformity and consistent application of the highway infrastructure, including traffic control devices.

Section 5A.02 Overview of ~~Connected and Automated~~Driving Automation System-Equipped Vehicles

Support:

~~Connected vehicle technology enables cars, buses, trucks, trains, roads and roadside infrastructure, as well as other devices such as cellular telephones, to communicate with one another. This technology enables every vehicle on the road to be aware of where other nearby vehicles are. Drivers would receive notifications and alerts of dangerous situations, such as a vehicle about to run a red traffic signal as it nears an intersection or an oncoming car, out of sight beyond a curve, swerving into the opposing lane to avoid an object on the road.~~

~~AV~~ Driving automation technology automates ~~some or all aspects~~part or all of the dynamic driving task (DDT)~~s~~ to assist or replace the human vehicle operator. ~~Automated~~ Driving automation ~~vehicle~~ features ~~may include~~ provide sustained partial or complete driving automation both between and across events in the driving environment. They include adaptive cruise control, ~~adaptive headlights, automatic emergency braking, lane tracking assist, or other technology based features used to control some or all aspects of the vehicle~~lane keeping assistance, and level 2 features, such as automated parking, traffic jam assistance and highway assistance (see SAE J3063_202103™). In the ~~near~~ future, ~~AVs are~~ vehicles equipped with Automated Driving System (ADS) features that are capable of performing the complete DDT while engaged, will be commercially deployed, both in conventional vehicles intended to be sold and leased to the general public, as well as in commercial ride-hailing and delivery fleets capable of driverless operation. ~~in which at least one element of vehicle control (e.g. steering, speed control, braking) occurs without direct driver input.~~

ADS-operated vehicles~~AVs~~ ~~work by gathering~~rely on information

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Commented [BW3]: Redrafted both to use standardized language and to correct a frequent misconception, which is that active safety intervention features, such as AEB ESC and LKAS, are "driving automation" features – they are not. Per J3016 (Scope):
Active safety systems, such as electronic stability control (ESC) and automatic emergency braking (AEB), and certain types of *driver* assistance systems, such as lane keeping assistance (LKA), are excluded from the scope of this *driving automation* taxonomy because they do not perform part or all of the *DDT* on a *sustained* basis, but rather provide momentary intervention during potentially hazardous situations. Due to the momentary nature of the actions of *active safety systems*, their intervention does not change or eliminate the role of the *driver* in performing part or all of the *DDT*, and thus are not considered to be *driving automation*, even though they perform automated functions. In addition, systems that inform, alert, or warn the *driver* about hazards in the driving environment are also outside the scope of this *driving automation* taxonomy, as they neither automate part or all of the *DDT*, nor change the *driver*'s role in performance of the *DDT* (see 8.13).

from a suite of sensors[1] in order to safely function in on-road traffic:

A. Cameras;

B. Radar;

C. Light detection and ranging (LiDAR);

D. Ultrasonic; and

E. Infrared.

ADS-operated vehicles ~~AVs~~ may combine sensor data with other inputs including detailed map data and information from ~~other connected vehicles or~~ infrastructure. ADS-operated vehicles ~~AVs~~ may be able to detect and classify objects in their surroundings and may predict how they are likely to behave.

Section 5A.03 Definitions and Terms

Support:

The following terms and definitions ~~and terms~~, found primarily in ~~the Society of Automotive Engineers standard~~ SAE J3016_202104 ™/-ISO ~~version of J3016 and other sources (aka, ISO/SAE PAS 22736)~~,here after referenced as J3016, are used extensively in describing and categorizing automated ~~vehicle~~ driving technology. ~~Their~~ These terms and definitions are ~~summarized for~~reproduced here for reference ~~and for use with~~when using ~~the provisions of~~ this Manual:

[1] "This list of sensing technologies is broadly reflective of currently-deployed driving automation system sensing technologies. However, this is a rapidly-developing field and new sensing variants, as well as all-new sensing technologies, are expected to emerge in the foreseeable future. Such technology development fluidity supports the need for more frequent updates of Part 5 of the MUTCD."

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A. Automated Driving System~~s~~ (ADS) - The hardware and software that are collectively capable of performing the entire dynamic driving task (DDT) on a sustained basis, regardless of whether it is limited to a specific operational design domain (ODD); this term is used specifically to describe a level 3, 4, or 5 driving automation system ~~(DAS)~~. (SAE J3016)

B. Advanced Driver Assistance Systems (ADAS) – are electronic control systems that ~~aid~~ support a vehicle driver in the performance of the DDT ~~with one or more driving tasks while driving~~. They are intended to ~~increase~~ enhance safe operation of a vehicle by a human driver and include~~s~~ ~~applications~~ features such as automatic braking, lane keeping assistance, adaptive cruise control, and others.

C. Driving Automation Levels:

1. Level or Category 0 - The performance by the driver of the entire DDT, even when enhanced by active safety systems~~The full-time performance by the human driver of all aspects of the DDT, even when enhanced by warning or intervention systems~~. (SAE J3016)
2. Level or Category 1 - The sustained and ODD-specific execution by a driving automation system of either the lateral or the longitudinal vehicle motion control subtask of the DDT (but not both simultaneously) with the expectation that the driver performs the remainder of the DDT~~The driving mode specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver performs all remaining aspects of the DDT~~. (SAE J3016)
3. Level or Category 2 - The sustained and ODD-specific execution by a driving automation system of both the lateral and longitudinal vehicle motion control subtasks of the DDT with the expectation that the driver completes the OEDR subtask and supervises the driving automation system~~The driving mode specific execution by one or more driver assistance systems of both steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver performs all remaining aspects of the DDT~~. (SAE J3016)
4. Level or Category 3 - The sustained and ODD-specific performance by an ADS of the entire DDT under routine/normal operation (see 3.27) with the expectation that the DDT fallback-ready user is receptive to ADS-issued requests to intervene, as well as to DDT performance-relevant system failures in other vehicle systems, and will respond appropriately~~The driving mode specific performance by an ADS of all aspects of the DDT with the expectation that the human driver will respond appropriately to a request to intervene~~. (SAE J3016)
5. Level or Category 4 - The sustained and ODD-specific performance by an ADS of the entire DDT and DDT fallback'~~The driving mode specific performance by an ADS of all aspects of the DDT, even if a human driver does not respond appropriately to a request to intervene~~. (SAE J3016)
6. Level or Category 5 - The sustained and unconditional (i.e., not ODD-specific) performance by an ADS of the entire DDT and DDT fallback~~The full-time performance by an ADS of all aspects of the DDT under all roadway and environmental conditions that can be managed by a human driver~~. (SAE J3016)

D. Cooperative Driving Automation – Automation that uses machine-to-machine (M2M) communication to enable cooperation among two or more entities with capable communications technology and is intended to facilitate the safer, more efficient movement of road users, including enhancing performance of the DDT for a vehicle with driving automation feature(s) engaged~~technology that enables communication with other vehicles and the infrastructure to coordinate automated vehicle operation~~. (SAE J3216_202005 ™)

E. Driving automation ~~A~~system~~S~~ or technology - The hardware and software that are collectively capable of performing part or all of the DDT on a sustained basis; this term is used generically to describe any system capable of level 1-5 driving automation. (SAE J3016)

F. Dynamic driving task (DDT) - All of the real-time operational and tactical functions required to operate a vehicle in on-

Commented [BW4]: Use of acronym for "driving automation system" explicitly rejected by J3016 in order to maintain clear separation between generic term "driving automation system: (L1-5) and ADS, namely 3-5, specifically, since these levels perform the complete DDTY while engaged.

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road traffic, excluding the strategic functions such as trip scheduling and selection of destinations and waypoints. (SAE J3016)

G. Operational design domain (ODD) - Operating conditions under which a given ~~DAS~~ driving automation system or feature thereof is specifically designed to function, including, but not limited to, environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics. (SAE J3016)

Section 5A.04 Traffic Control Device Design and Use Considerations

Support:

The interaction of traffic control devices with ~~DAS~~ driving automation systems can create many challenges for agencies in determining traffic control device selection and application. The lack of tolerance of driving automation systems ~~DAS~~ for non-uniformity in traffic control device design and application is a limiting factor of current driving automation system~~DAS~~ sophistication, i.e. driving automation system ~~DAS~~ has limited ability to interpolate across gaps in traffic control device cues to the vehicle in the following situations:

A. The driving automation system's ~~DAS technologies~~ ability to adapt to existing traffic control device design and typical quality, e.g. the refresh rates of electronic changeable message sign displays or the overall quality of a device that has been out on the roadway for many years;

B. The color perception of signs;

C. The electronically perceptible conspicuity and contrast of markings in different environments and lighting conditions;

D. ~~The~~ Driving automation system ~~DAS~~ camera technologies and device photometric characteristics in reading various types of traffic signals

E. The ability to discern and comprehend temporary traffic control devices and their varying applications, e.g. active electronic display devices, flaggers, etc.;

F. The ability to decipher traffic control at rail grade crossings, especially with passive control.

These and other challenges might limit the functionality of driving automation systems ~~DAS~~ making them less effective or functional. The uniform design and consistent application of standardized traffic control devices supports the functionality of driving automation ~~DAS~~ technology in many situations. Similarly, good traffic control device maintenance practices and programs will help improve the potential for ~~vehicle~~ driving automation systems ~~DAS~~ to operate properly in many roadway environments.

Guidance:

Agencies should adopt traffic control device maintenance policies and or practices with consideration to both the human vehicle operator and driving automation ~~DAS~~ technology needs (see Sections 1A.12, 2A.18, 3A.05 and 4A.10 of this Manual).

Engineering judgment (see Section 1D.03 of this Manual) used to determine traffic control device selection and placement should consider uniformity in application and location needed to support both the human vehicle operator and driving automation ~~DAS~~ technology.

Support:

A systematic approach to traffic control device selection, application, and maintenance taking into consideration certain fundamental principles, will help agencies considering the inclusion of driving automation system-equipped~~DAS~~ vehicles on their roadways. Generally, improvements to traffic control device uniformity and improved maintenance policies and practices that keep traffic control devices in good working order with high levels of conspicuity that benefit the human vehicle operator will benefit driving automation system-equipped ~~DAS~~ vehicles as well.

Guidance:

Agencies should apply the following fundamental principles and considerations as they evaluate traffic control devices and other maintenance practices to support ~~AV~~ driving automation technologies during maintenance and infrastructure improvements:

A. The uniform and consistent application of traffic control devices on each type of roadway; applying a similar approach to traffic control at similar locations in similar situations.

B. Established maintenance policies that incorporate effective practices to ensure the clear message intended to the road user on traffic control devices reaching the end of their useful life, or are damaged or otherwise no longer serviceable, be identified, fixed or replaced in a timely manner.

C. Temporary or emergency traffic control, to the extent practical, is planned in advance using devices that comply with the provisions of this Manual and following policies designed to ensure uniformity throughout the site and across jurisdiction.

D. Removal of extraneous devices that are no longer necessary or that provide limited benefit to vehicle operation or navigation.

CHAPTER 5B. PROVISIONS FOR TRAFFIC CONTROL DEVICES

Section 5B.01 Signs

Support:

Driving automation systems ~~DAS~~ use~~s~~ machine vision technology to locate, read, and comprehend traffic signs and appropriately make vehicle operational decisions. Location, condition, uniformity, design characteristics, and consistent application all affect the ability of machine vision to perform these functions.

Guidance:

Sign location and application should be clearly associated with the displayed message to the specific lane or road to which it applies, such as in the case of parallel roads or lanes with different speed limits or restrictions.

The practice of sign and information spreading (see Section 2A.19) should be used to limit the amount of information displayed in one location or on one sign to minimize sign clutter.

Use of signs with designs that are otherwise not provided for in this Manual or the Standard Highway Signs publication should be avoided to prevent misdetection by driving automation systems. ~~Signs with designs that are otherwise not provided for in this Manual or the Standard Highway Signs publication should use standardized sign design practices and features as provided for in this Manual for the type of sign, the location, and character of the roadway on which it is used.~~

The illuminated portion of electronic-display signs using LEDs should have a standard refresh/flicker rate. The refresh rate of the LEDs should be greater than 200 Hz to be easier for the camera to detect.

Section 5B.02 Markings

Support:

Driving automation systems ~~DAS~~ use~~s~~ machine vision technology to locate, read and comprehend pavement markings. Location, condition, uniformity, design characteristics, and consistent application all have some effect on the ability of machine vision to perform this function. Certain pavement marking applications and practices have been shown through research to better support driving automation technology~~AV operations~~, while also benefiting, or at least not detracting from, the performance of the human operator. Such practices include the following:

A. Normal-width longitudinal lines on freeways, expressways, and ramps of at least 6 inches wide (see Section 3A.04).

B. Edge lines of at least 6 inches in width on roadways with posted speeds greater than 40 mph (see Section 3B.09).

Guidance:

The following should be considered to better accommodate machine vision used to support driving automation system-equipped vehicles~~the automation of vehicles~~:

A. Normal-width longitudinal lines of at least 6 inches wide on conventional roadways.

B. Edge lines of at least 6 inches in width on conventional roadways with posted speeds of 40 mph or less.

C. Dotted edge line extensions along all entrance and exit ramps, all auxiliary lanes, and all tapers where a deceleration or auxiliary lane is added (see Section 3B.11).

D. Chevron markings (see Section 3B.25) in the neutral areas of exit gores to distinguish them from travel lanes.

E. Continuous markings at the beginning of work zones and in all lane transitions.

F. Raised pavement markers only as a supplement to, rather than as a substitute for, markings (see Sections 3B.16 and 3B.17).

G. Uniform contrast markings on light-colored pavements to create greater contrast.
H. Broken lines (see Section 3B.06) of at least 10 ft in length with a maximum gap of 30 ft.
I. Avoidance of decorative elements mid-block, in crosswalks, and within intersections.

Section 5B.03 Highway Traffic Signals

Guidance:

The following considerations should be used to better accommodate machine vision used to support driving automation system-equipped ~~the automation of~~ vehicles and benefit the performance of the human vehicle operator:

A. Traffic signal design should be consistent along corridors with respect to the placement of signal faces overhead on span-wire and mast arms versus post-mounting on the side of the roadway.

B. The number of signal faces for approach lanes and the selection of signal indications and signal clusters should be consistent along a corridor to promote uniform displays for identical or similar situations.

C. The refresh rate of the LED traffic signals should be consistent throughout the jurisdiction and be greater than 200 Hz to allow greater consistency in machine vision detection.

Support:

Achieving uniformity along a corridor is desirable for machine vision technology, but can be challenging. Multiple options are available for traffic signal displays to allow design variations based on specific intersection variables such as available overhead clearance, utility conflicts, signal support design

constraints and other factors. Where possible, vehicle-to-infrastructure communication (V2I) can complement driving automation systems traffic signal recognition to provide redundancy, and to improve reliability and accuracy.~~Where possible, connected and automateddriving automation system-equipped vehicles (CAV) needs with~~

~~respect to traffic signals are better addressed through vehicle to infrastructure (V2I) for the reasons stated above and for reliability and accuracy of critical communications under all environmental conditions.~~

Section 5B.04 Temporary Traffic Control

Guidance:

Considerations should be given to better accommodate machine vision used to support driving automation system-equipped ~~the automation of~~ vehicles and benefit the performance of the human vehicle operator in and through work zones.

The type of signs, spacing and mounting height should follow the requirements of Section 6B.04 Advance Warning Area and 6F.02 Sign Placement. The END ROAD WORK (G20-2) sign should be used to establish the end of the work zone.

Standard:

Existing pavement markings shall be maintained in all long-term stationary (see Section 6G.02) temporary traffic control zones in accordance with Chapters 3A and 3B, except as otherwise provided for temporary pavement markings in Section 6F.78. Pavement markings shall match the alignment of the markings in place at both ends of the TTC zone. Pavement markings shall be placed along the entire length of any paved detour or temporary roadway prior to the detour or roadway being opened to road users.

For long-term stationary operations, pavement markings in the temporary traveled way that are no longer applicable shall be removed or obliterated as soon as practical. Pavement marking obliteration shall remove the non-applicable pavement marking material, and the obliteration method shall minimize pavement scarring. Painting over existing pavement markings with black paint or spraying with asphalt shall not be accepted as a substitute for removal or obliteration. When not applicable, signs within temporary traffic control zones should be covered up so that are not "readable" by machine-vision sensors.

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Guidance:

To better accommodate machine vision used to support the driving automation system-equipped ~~automation of~~ vehicles, channelizing devices should be at least 8 inches wide with retroreflective material for reliable machine detection in all *weather conditions. Markings entering the work zone and through lane shifts should be made with highly visible and continuous materials, not intermittent buttons and reflectors. To increase safety, V2I communications should be enabled in work zones to communicate to vehicles the presence of a work zone.*

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Section 5B.05 Traffic Control for Railroad and Light Rail Transit Grade Crossings

Guidance:

For passive and active grade crossings, placement of signs and markings should be consistent along a corridor to promote uniformity and to improve the ability of machine vision technology to recognize highway-rail grade crossings.

For active grade crossings, V2I communication should be used to relay information on the arrival or presence of a train at a highway-rail grade crossing.

To better accommodate machine vision used to support the driving automation system-equipped ~~automation of~~ vehicles, the signs and pavement markings associated with railroad crossings and tracks that are no longer active should be removed.

Support:

Where possible, V2I communication can complement automated driving system highway-rail grade crossing recognition to provide redundancy, and to improve reliability and accuracy. ~~Where possible, CAV driving automation system-equipped vehicle needs with respect to highway-rail grade crossings are better addressed through V2I infrastructure for reasons of reliability and accuracy of critical communications under all environmental conditions.~~

Section 5B.06 Traffic Control for Bicycle Facilities

Guidance:

To better accommodate machine vision used to support the driving automation system-equipped ~~automation of~~ vehicles, bicycle facilities should be segregated from other vehicle traffic using physical barriers where practicable.

Road markings should indicate the end of a bike lane that is merged with other traffic.

What about pedestrian crosswalks? Especially problematical are novel designs:

CHAPTER 5C. FUTURE CONSIDERATIONS

SAE International requests that FHWA create a Section 5C, “Traffic Control Device Digital Infrastructure”. NPA Part 5, Automated Vehicles, includes references to the potential benefit of connected vehicle (CV) technologies. Specific areas where using CV is preferable to reliance on physical traffic control devices alone include signal phase and timing (SPaT), work zone data and rail crossing signal actuation. Just as traffic control devices use color, shapes, symbols, words, sounds, and/or tactile information to communicate specific regulatory, warning or guidance messages to road users; vehicle-to-everything (V2X) wireless communication protocols allow static and dynamic traffic control device location and messages to be exchanged. This digital twinning of traffic control device messaging provides new tools for the traffic engineer’s toolbox. The development and inclusion of references to this type of digital information exchange within Section 5C, integrates traffic engineering into the broader field of transportation digital infrastructure. SAE supports the inclusion of these examples within the NPA and requests that these being included within the requested Section 5C for traffic control device digital infrastructure.

SAE offers our assistance to work with FHWA to identify key protocols and standards capable of V2X communication of traffic control messages. SAE International J2735™, for example, specifies digital message sets, data frames and data elements. While several dynamic messaging cases were raised in the NPA, digital twinning has potential benefits relative to installation and communication of static traffic control devices as well. Creating a digital infrastructure section within the Manual on Uniform Traffic Control Devices (MUTCD) Part 5, opens the door to exploring how we might accelerate the value of digital infrastructure to improve the accuracy of navigation and high-definition maps.