RATIONALE

This revision of SAE J3216 includes:

- Clarification of the scope of Cooperative Driving Automation (CDA) within the broader "Connected and Automated Vehicle (CAV)" context.

- New and revised terms and definitions to reconcile issues identified during J-doc development efforts under the CDA Committee, as well as ongoing revisions to SAE J3016.

1. SCOPE

This document describes machine-to-machine (M2M)[1] communication to enable cooperation between two or more traffic participants or CDA devices hosted or controlled by said traffic participants. The cooperation supports or enables performance of the dynamic driving task (DDT) for a subject vehicle equipped with an engaged driving automation system feature and a CDA device. Other participants may include other vehicles with driving automation feature(s) engaged, shared road users (e.g., drivers of conventional vehicles or pedestrians or cyclists carrying compatible personal devices), or compatible road operator devices (e.g., those used by personnel who maintain or operate traffic signals or work zones).

Cooperative driving automation (CDA) aims to improve the safety and flow of traffic and/or facilitate road operations by supporting the safer and more efficient movement of multiple vehicles in proximity to one another. This is accomplished, for example, by sharing information that can be used to influence (directly or indirectly) DDT performance by one or more nearby road users. Vehicles and infrastructure elements engaged in cooperative automation may share information, such as state (e.g., vehicle position, signal phase), intent (e.g., planned vehicle trajectory, signal timing), or seek agreement on a plan (e.g., coordinated merge). Cooperation among multiple participants and perspectives in traffic can improve safety, mobility, situational awareness, and operations. However, nothing in this document is intended to suggest that driving automation requires such cooperation in order to be performed safely.

Cooperative strategies may be enabled by the sharing of information in a way that meets the needs of a given CDA Feature. The needs may be expressed in terms of performance characteristics, such as latency, information flow, range, privacy and security, and information content and quality. There are several potential technologies for communicating information between a subject vehicle(s) and other traffic participants.

---

[1] CDA communications are necessarily M2M and are unmediated by human road users so that near real-time safety objectives can be achieved.

When referring to a CDA Feature, the word "feature" here varies from its common English definition. To emphasize this variance and to avoid confusion, "Feature" is capitalized when modified by the adjective "CDA" or "C-ADS."

This document focuses on CDA Feature-oriented functionality and does not imply use of any specific communications protocols. This document addresses the performance of functions and actions in conducting the DDT (refer to the current version of ISO/SAE PAS 22736/SAE J3016) by the ADS. This information report is intended to facilitate communication and awareness for the design and anticipated development and validation of CDA Features.

2. REFERENCES

2.1   Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1   SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J3016   Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles

SAE J3251   Cooperative Driving Automation (CDA) Feature: Perception Status Sharing for Occluded Pedestrian Collision Avoidance

SAE J3256   Cooperative Driving Automation (CDA) Feature – Infrastructure-Based Prescriptive Cooperative Merge

SAE J3282   Cooperative Infrastructure CDA Feature: Cooperative Permissive Left Turn Across Opposing Traffic with Infrastructure Guidance

2.1.2   IEEE Publications

Available from IEEE Operations Center, 445 and 501 Hoes Lane, Piscataway, NJ 08854-4141, Tel: 732-981-0060, www.ieee.org.

IEEE 1609.2   IEEE Standard for Wireless Access in Vehicular Environments - Security Services for Application and Management Messages

2.1.3   ISO Publications

Copies of these documents are available online at https://webstore.ansi.org/.

ISO/SAE PAS 22736   Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles

ISO 23374-1   Intelligent transport systems — Automated valet parking systems (AVPS) — Part 1: System framework, requirements for automated driving and for communications interface

2.1.4   Other Publications

5G-PPP. (2017). *5GCAR Scenarios, Use Cases, Requirements and KPIs*. 5GCAR project deliverable D2.1, Tech. Rep.

Albus, J.S., Huang, H.-M., Messina, E.R., Murphy, K., Juberts, M., Lacaze, A., Balakirsky, S.B., Shneier, M.O., Hong, T.H., Scott, H.A., Proctor, F.M., Shackleford, W.P., Michaloski, J.L., Wavering, A.J., Kramer, T., Dagalakis, N., Rippey, W.G., Stouffer, K.A., and Legowik, S. (2002). *4D/RCS: A reference model architecture for intelligent unmanned vehicle systems, version 2.0* (Report No. NISTIR 6910). Prepared for the Army Research Laboratory Demo III Program. National Institute of Standards and Technology. https://doi.org/10.6028/NIST.IR.6910.

Kosseff, J. (2018). Defining cybersecurity law. *Iowa Law Review*, *103*(985).

Lochrane, T. (2018, December 18). *Transforming the Transportation Industry with Cooperative Automation Research Mobility Applications (CARMA)* [PowerPoint slides]. Office of Operations Research and Development, Federal Highway Administration. https://transops.s3.amazonaws.com/uploaded_files/NOCoE%20CARMA%20Webinar%20Slides.pdf.

OECD. (2017). *OECD Handbook for Internationally Comparative Education Statistics*, Chapter 6. https://doi.org/10.1787/9789264279889-en.

2.2   Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1   SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J2735   V2X Communications Message Set Dictionary

SAE J2945   Dedicated Short Range Communication (DSRC) Systems Engineering Process Guidance for SAE J2945/X Documents and Common Design Concepts™

SAE J2945/1   On-Board System Requirements for V2V Safety Communications

SAE J2945/3   Requirements for Road Weather Applications

SAE J2945/5   Service Specific Permissions and Security Guidelines for Connected Vehicle Applications

SAE J3063   Active Safety Systems Terms and Definitions

2.2.2   Other Publications

5G-PPP. (2015). *Automotive Vertical Sector*. White Paper.

U.S. Department of Transportation. (2015). DSRC Report to Congress, Chapter 2.

U.S. Department of Transportation. (2018). Preparing for the Future of Transportation: Automated Vehicle 3.0 (AV 3.0), Appendix C. https://www.transportation.gov/sites/dot.gov/files/docs/policy-initiatives/automated-vehicles/320711/preparing-future-transportation-automated-vehicle-30.pdf.

U.S. Department of Transportation. (2020). Ensuring American Leadership in Automated Vehicle Technologies: Automated Vehicles 4.0 (AV 4.0). https://www.transportation.gov/sites/dot.gov/files/2020-02/EnsuringAmericanLeadershipAVTech4.pdf.

U.S. Department of Transportation. (2014). Traffic Monitoring Guide, Appendix C. VEHICLE TYPES, FHWA publication, last updated 11/7/2014. https://www.fhwa.dot.gov/policyinformation/tmguide/tmg_2013/vehicle-types.cfm.

3. ABBREVIATIONS AND ACRONYMS

The terms, abbreviations, and acronyms cited below shall be a part of the terms of this information report unless specifically cited otherwise.

ADS   Automated Driving System

ADS-DV   ADS-Dedicated Vehicle

C-ADS   Cooperative-Automated Driving System

CACC   Cooperative Adaptive Cruise Control

CARMA   Cooperative Automation Research Mobility Applications

CDA   Cooperative Driving Automation

CSP   Communication Service Provider

DDT   Dynamic Driving Task

FHWA   Federal Highway Administration

IOO   Infrastructure Owner/Operator

ITS   Intelligent Transportation System

M2M   Machine-to-Machine

ODD   Operational Design Domain

RSE   Roadside Equipment

SPaT   Signal Phase and Timing

TSMO   Transportation Systems Management and Operations

4. DEFINITIONS

4.1   AUTOMATED DRIVING SYSTEM (ADS)

Refer to the current version of ISO/SAE PAS 22736/SAE J3016.

4.2   COOPERATIVE DRIVING AUTOMATION (CDA)

Driving automation that uses M2M communications to support or enable cooperation among two or more entities with compatible 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 a driving automation feature(s) engaged. Remote control within protected environments, such as Automated Valet Parking Systems (AVPS) described in ISO 23374-1, are excluded from this definition.

NOTE 1: CDA can be used with SAE Levels 1 to 5 automation. For using CDA with SAE Levels 3 through 5, see 4.3. For using CDA with SAE Levels 1 and 2, see 4.4. A cooperative driving automation system describes any Level 1 to 5 driving automation system (as described in SAE J3016) that is capable of cooperation.

NOTE 2:   CDA communications are distinct from V2X communications, which support a broader set of applications than CDA Features. For example, ADAS applications enabled by V2X (e.g., emergency electronic brake light systems) are intended for human-operated vehicles. By contrast, CDA Features use machine-to-machine (M2M) communications (no human in the loop) specifically to enable two or more proximal traffic participants to automatically cooperate for immediate (possibly prolonged) effect in enhancing safety and/or mobility. As such, defined V2X message content, such as signal phase and timing (SPaT) or basic safety message (BSM) that is broadcast by itself is not a CDA Feature, although they may provide important information for executing a given CDA Feature.

NOTE 3:   For cooperative automated driving system-operated vehicles (see 4.3.2) engaged in CDA Feature execution, the M2M communications may enhance the performance of the DDT for the subject vehicle (e.g., object and event detection [OEDR] and response, operational, and tactical maneuvers).

NOTE 4:   For road operator CDA devices engaged in CDA Feature execution, the M2M communications may provide situational awareness and influence performance of traffic management (e.g., signal phase and timing [SPaT], dynamic speed limits, and emergency response).

4.3   COOPERATIVE AUTOMATED DRIVING SYSTEM (C-ADS)

An ADS capable of utilizing CDA.

4.3.1   COOPERATIVE AUTOMATED DRIVING SYSTEM (C-ADS)-EQUIPPED VEHICLE

A vehicle equipped with Level 3, 4, or 5 driving automation and capable of utilizing CDA. Note that Level 3 systems require human driver intervention upon ADS request. (Refer to SAE J3016 for additional information about driving automation systems.)

NOTE: CDA vehicle is inclusive of SAE Levels 1 to 5 automation, and C-ADS refers to SAE Levels 3 to 5 automation. See the example in 7.5.

4.3.2   COOPERATIVE AUTOMATED DRIVING SYSTEM (C-ADS)-OPERATED VEHICLE

An ADS-operated vehicle that is simultaneously engaging in the execution of a CDA Feature.

NOTE 1:   A C-ADS-Operated Vehicle is a C-ADS-Equipped vehicle when its CDA Feature is engaged.

NOTE 2:   Additional ADS functions that are not specifically part of executing a CDA Feature may also be actively engaged on a C-ADS-Operated Vehicle.

4.4   CDA DRIVER SUPPORT FEATURE

A Level 1 or 2 driving automation system capable of utilizing CDA. (Refer to SAE J3016 for additional information about driving automation systems.)

4.5   CDA FEATURE

The design-specific functionality supported or enabled by M2M cooperation among CDA devices communicating with one or more CDA vehicles engaging in executing a CDA Feature.

NOTE 1:   A given CDA Feature may entail the use of more than one class of CDA cooperation information (see 4.6.1 through 4.6.4). For example, a cooperative merge CDA Feature may entail Class C agreement-seeking cooperation among merging C-ADS-Operated Vehicles, as well as Class D prescriptive cooperation between a CDA-I device and merging C-ADS-Operated Vehicles.

NOTE 2:   CDA Features may be referred to by generic names (e.g., cooperative merging) or manufacturer-specific names.

4.5.1   SUPPORTING CDA FEATURE

A CDA Feature capable of promoting cooperation among traffic participants intended to augment performance of actions by road users and road operators.

EXAMPLE 1: A C-ADS-Operated Vehicle detects a pedestrian in a crosswalk and shares object classification and path prediction information with a second approaching C-ADS-Operated Vehicle. The approaching vehicle already had detected an object in the crosswalk but had not yet determined classification or path prediction for the object. The CDA communication provides advance information about the pedestrian for the approaching vehicle to proactively adjust vehicle operation for enhanced safety and efficiency by preventing sudden emergency maneuvers.

EXAMPLE 2: A C-ADS-Operated Vehicle receives SPaT information from a CDA-I device, thereby supporting planning and optimization of approach and departure by the vehicle to reduce congestion and travel time and enhance efficiency.

4.5.2   ENABLING CDA FEATURE

A CDA Feature capable of promoting cooperation among traffic participants intended to facilitate the performance of actions by road users and road operators that they would otherwise not be able to perform.

NOTE: The execution of Enabling CDA Features results in a different outcome than could have been achieved without the Enabling CDA Feature (e.g., detect occluded object, achieve target lane position, expand ODD, etc.).

EXAMPLE 1: While approaching a crosswalk, a C-ADS-Operated Vehicle detects a pedestrian in the crosswalk and shares information with a second approaching C-ADS-Operated Vehicle about the location, speed, and heading of the pedestrian, which is occluded by the detecting C-ADS-Operated Vehicle. Without the information provided by the detecting (and occluding) C-ADS-Operated Vehicle, the second C-ADS-Operated Vehicle may not have detected the pedestrian in time to avoid colliding with it. Based on the shared pedestrian information, the second vehicle is able to plan appropriate maneuvers to ensure all participants' safety.

EXAMPLE 2: A CDA Feature enables coordinated intersection departure by means of an infrastructure device providing C-ADS-Operated Vehicles with SPaT information allowing nearby C-ADS-Operated Vehicles to coordinate their departure timing and velocity trajectory for enhanced safety and efficiency.

EXAMPLE 3: A CDA Feature enables closely spaced vehicle platooning movements by exchanging information about desired velocity and headway among vehicles.

EXAMPLE 4: A CDA Feature enables cooperative merging whereby a subject C-ADS-Operated Vehicle uses M2M communication to request a desired lane position and maneuvers from nearby C-ADS-Operated Vehicles, such as slowing down to allow the subject vehicle to move from an on-ramp to a highway. Due to coordinated maneuvers enabled by CDA, merging can be conducted smoothly, without negatively affecting traffic flow.

4.6   CDA COOPERATION CLASSES

Classes of cooperation facilitated by M2M communications among CDA devices that may influence DDT performance and traffic operations, defined as Classes A through D based on the increasing amount of cooperation entailed in each successive class.

NOTE: The use of CDA information to influence DDT performance by one or more C-ADS-Operated Vehicles in any given situation depends upon the type of information provided (see 4.6.1 through 4.6.4), as well as other information used by the C-ADS-Operated Vehicle(s).

4.6.1   STATUS-SHARING COOPERATION (CLASS A)

Perception information about the traffic environment and information about the sending entity provided by the sending entity for potential utilization by receiving entities. ("Here I am, and here is what I see.")

NOTE 1:   Status-sharing cooperation does not require the ability or consent of transmitting entities to employ the information provided via M2M communication, which may originate from any nearby traffic participant.

NOTE 2:   Status-sharing cooperation may be used to confirm or enhance an entity's situational awareness.

EXAMPLE 1:   A CDA device carried by a VRU transmits its location, speed, and heading to C-ADS-Operated Vehicles that may be operating in the vicinity.

EXAMPLE 2:   A C-ADS-Operated Vehicle shares its current velocity and the velocity of the vehicle immediately in front with nearby vehicles. A C-ADS-Operated Vehicle behind the status-sharing vehicle adjusts its speed to improve traffic flow and safety.

EXAMPLE 3:   Cooperative situational awareness whereby a roadside equipment CDA device at a crosswalk communicates to nearby vehicles information that a pedestrian is approaching the crosswalk. A nearby C-ADS-Operated Vehicle receives the information, which it may use, along with information provided by the ADS's sensors, to plan the DDT performance near the crosswalk.

4.6.2   INTENT-SHARING COOPERATION (CLASS B)

Information about planned future actions of the sending entity provided by that entity for potential utilization by receiving entities. ("This is what I plan to do.")

NOTE 1:   Intent-sharing cooperation does not require the ability or consent of receiving entities to employ the information provided via M2M communication, which may originate from any nearby traffic participant.

NOTE 2:   Receiving entities do not necessarily need to act on the shared intent, and all entities are expected to conduct competent operations regardless of others' actions.

NOTE 3:   Intent-sharing cooperation may be used to augment prediction of future states to enhance models of the planned future actions of the sending entity.

EXAMPLE 1:   A C-ADS-Operated Vehicle with an engaged Level 3 highway feature transmits its intention to change lanes with proximal traffic participants to facilitate safer and more efficient traffic flow in the immediate vicinity. A proximal C-ADS-Operated Vehicle with an engaged Level 4 highway feature receives the lane change intention information and slows down to maintain a desired longitudinal distance when the Level 3 C-ADS-Operated Vehicle merges into the lane ahead.

EXAMPLE 2:   A CDA device located at/near a traffic signal transmits signal phase and timing (SPaT) information to proximal road users to facilitate eco-drive functionality. A C-ADS-Operated Vehicle using a Level 3 feature approaching the traffic signal uses the SPaT information to adjust longitudinal vehicle motion control to reduce braking and acceleration.

4.6.3   AGREEMENT-SEEKING COOPERATION [AMONG CDA DEVICE AGENTS] (CLASS C)

A sequence of information exchanges between two or more proximal CDA devices that are intended to influence the motion control planning of specific C-ADS-Operated Vehicles. ("Let's do this together.")

NOTE 1:   Agreement-seeking cooperation requires the ability and authority of the CDA device agents involved to cooperate and agree on plan(s) based on the information exchanged via M2M communication. Both transmitting and receiving traffic participants must host CDA devices.

NOTE 2:   Agreement-seeking cooperation includes an interactive exchange of information that may include plans, acceptance or rejection of plans, or considerations for arriving at consensus on a proposed plan. Depending on circumstances, CDA device agents may not follow a planned future action, and all entities must conduct competent operations regardless of others' actions.

EXAMPLE 1:   Cooperative merging (see Figure 1) of C-ADS-Operated Vehicle 1 between C-ADS-Operated Vehicle 2 and C-ADS-Operated Vehicle 3 that currently occupy an adjacent lane may be conducted in the following steps: (1) C-ADS-Operated Vehicle 1 indicates a plan to merge via intent-sharing cooperation with C-ADS-Operated Vehicles 2 and 3; (2) C-ADS-Operated Vehicle 1 shares a proposed action that would enable a merging maneuver, e.g., specified longitudinal spacing between C-ADS-Operated Vehicles 2 and 3 so that C-ADS-Operated Vehicle 1 may change lanes; (3) C-ADS-Operated Vehicles 2 and 3 indicate willingness to engage in agreement-seeking cooperation. This may result in multiple outcomes:

Scenario A: C-ADS-Operated Vehicles 2 and 3 acknowledge consent to allow the proposed action, and all entities conduct competent operations while executing the intended maneuvers (i.e., C-ADS-Operated Vehicle 3 slows down, and/or C-ADS-Operated Vehicle 2 speeds up, and C-ADS-Operated Vehicle 1 changes lanes).

Scenario B: C-ADS-Operated Vehicle 2 and/or C-ADS-Operated Vehicle 3 share intent not to allow the proposed action or goal, and C-ADS-Operated Vehicle 1 does not execute the intended maneuver.
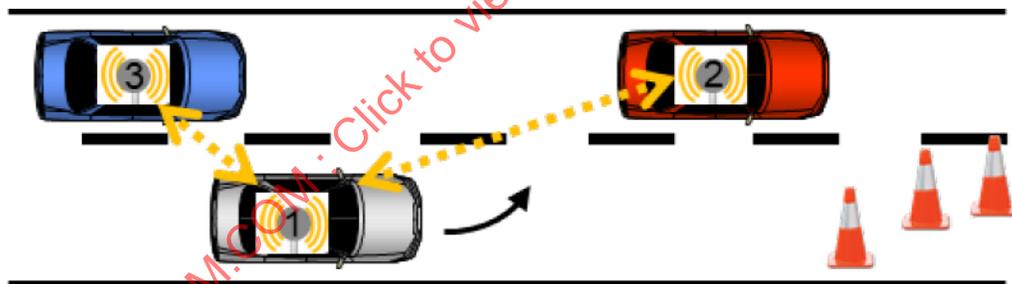

Figure 1 - Cooperative merging example

EXAMPLE 2:   Cooperative intersection departure whereby: (1) a CDA device representing the traffic management authority provides SPaT information to nearby road users; (2) C-ADS-Operated Vehicles stopped at the intersection receive the SPaT information, and the second-in-line C-ADS-Operated Vehicle requests to engage in agreement-seeking cooperation with the first-in-line C-ADS-Operated Vehicle; (3) the first-in-line C-ADS-Operated Vehicle agrees to engage in agreement-seeking cooperation; (4) the second-in-line C-ADS-Operated Vehicle proposes an acceleration and final velocity for departing the intersection based on SPaT information; (5) the first-in-line C-ADS-Operated Vehicle agrees to the proposed acceleration and final velocity; (6) both C-ADS-Operated Vehicles conduct competent operations while following the agreed-upon acceleration and final velocity resulting in a safer and more efficient intersection navigation.

EXAMPLE 3: Cooperative stop sign intersection management for two C-ADS-Operated Vehicles arriving coincidentally from opposing directions may be conducted in the following steps: (1) C-ADS-Operated Vehicle 1 indicates intent to engage in agreement-seeking cooperation; (2) C-ADS-Operated Vehicle 2 agrees to engage in agreement-seeking cooperation; (3) C-ADS-Operated Vehicle 1 shares intent to perform a left-hand turn maneuver and C-ADS-Operated Vehicle 2 shares intent to perform a straight forward maneuver; (4) C-ADS-Operated Vehicle 1 provides a plan that it goes first and C-ADS-Operated Vehicle 2 goes second; (5) C-ADS-Operated Vehicle 2 agrees to the plan; and (6) both C-ADS-Operated Vehicles conduct competent operations while executing the plan (i.e., C-ADS-Operated Vehicle 1 makes the left-hand turn and then C-ADS-Operated Vehicle 2 drives straight). This coordination results in a shorter overall time for both vehicles to navigate the intersection and avoids potential conflicts.

4.6.4   PRESCRIPTIVE COOPERATION (CLASS D)

The direction provided by a CDA device of specific action(s) to be taken by specific traffic participants for imminent performance of the DDT or performance of a particular task by a road operator (e.g., changing traffic signal phase), provided by a CDA device agent(s) having the requisite authority to expect compliance and thus adhered to by a receiving CDA device(s)/agent(s). ("I will do as directed.")

NOTE 1:   Prescriptive cooperation does not require the willingness of the affected CDA devices/agents to cooperate. Rather, it relies on business/contractual or legal authority to expect CDA devices/agents to execute the commands (provided safety can be maintained), such as a specific aspect of DDT performance, under particular circumstances.

NOTE 2:   Prescriptive cooperation may be performed by transportation authorities and/or fleet operations centers communicating with fleet vehicles under their control.

NOTE 3:   Transportation authorities may have the ability to direct prescriptive cooperation to any relevant traffic participants.

NOTE 4:   Prescriptive cooperation may utilize status-sharing, intent-sharing, and agreement-seeking cooperation to provide context for the understanding to cede control over actions that relate to the DDT performance.

EXAMPLE 1:   Cooperative incident scene management whereby a CDA device associated with incident response communicates a geofenced area that is temporarily closed to traffic and a reduced speed limit that is not to be exceeded. Surrounding C-ADS-Operated Vehicles use this information to perform the DDT in accordance with the reduced speed limit within that geo-fenced area.

EXAMPLE 2:   An emergency vehicle directs a C-ADS-Operated Vehicle to vacate its lane to an unoccupied lane or road shoulder, or to stop (or remain stopped) at an intersection on a green light in order to yield to the emergency vehicle.

EXAMPLE 3:   An emergency vehicle directs a traffic control signal to change phase to green in order to facilitate faster arrival at a hospital emergency ward.

4.7   CDA DEVICE

A device equipped with requisite M2M communication technology that is used by traffic participants to execute CDA Feature(s).

4.8   CDA DEVICE AGENT

A traffic participant that authorizes its CDA device to send and receive communications enabling traffic participants to engage in CDA and authorizes CDA-related actions.

NOTE: A CDA device agent is distinct from a CDA device user or host, although the two may coincide in some cases. For example, in the case of a CDA device worn or carried by a VRU, the device agent is the device manufacturer, rather than the VRU/device user. Similarly, in the case of a conventional vehicle equipped with a CDA device, the device agent is the original equipment vehicle manufacturer, rather than the vehicle owner or driver/user. In the case of an infrastructure-based CDA device, the device agent and the user/host may be the same entity, namely, a state or local agency that serves as the infrastructure owner/operator (IOO) for the device.

4.9   CDA INFRASTRUCTURE (CDA-I)

Infrastructure capable of engaging in CDA Feature execution.

NOTE 1: CDA infrastructure can be located near a roadside (commonly referred to as "edge computing") as well as far away from a roadside (commonly referred to as "cloud computing").

NOTE 2: The CDA device agent for CDA-I is typically an infrastructure owner-operator with legal jurisdiction. For example, the CDA-I device is typically an RSU.

NOTE 3: The CDA device for a vehicle is typically an OBU.

NOTE 4: The CDA device for a pedestrian is typically an MU.

4.10   [CDA] MACHINE-TO-MACHINE (M2M) COMMUNICATION

Information exchanged wirelessly between two or more CDA devices in support of CDA Feature execution.

NOTE: CDA communications are necessarily M2M and are unmediated by human road users so that near real-time safety objectives can be achieved.

4.11   DRIVING AUTOMATION

Refer to the current version of ISO/SAE PAS 22736/SAE J3016.

4.12   DRIVING AUTOMATION SYSTEM OR TECHNOLOGY

Refer to the current version of ISO/SAE PAS 22736/SAE J3016

4.13   DYNAMIC DRIVING TASK (DDT)

Refer to the current version of ISO/SAE PAS 22736/SAE J3016.

4.14   OPERATIONAL DESIGN DOMAIN (ODD)

Refer to the current version of ISO/SAE PAS 22736/SAE J3016.

4.15 [A] PLAN

A sequence of tasks defined to achieve or maintain a DDT-relevant goal during a trip.

NOTE 1: Planning may occur at strategic, tactical, and operational timescales. This may include outputs from mission planning (e.g., selected route segments and strategies to achieve a given destination or waypoint given certain goals) and behavior planning (e.g., trajectory—i.e., path and speed—of vehicles to competently perform the DDT given a particular driving situation).

NOTE 2: The terms task, goal, and trip are not further defined here. These concepts are discussed in other documents, such as the NIST 4D-RCS Framework provided in the references.

4.16 TRAFFIC PARTICIPANT

Entities whose actions influence travel in the transportation environment, including road users engaged in travel upon or across publicly accessible roadways, road operators, certificate authorities, and communications service providers (CSPs), each of which is defined in the following four subsections.

4.16.1 ROAD USERS

A traffic participant on or adjacent to an active roadway for the purpose of travelling from one location to another.

NOTE 1: Road users may include motor vehicles (including emergency vehicles), vehicle occupants, pedestrians, pedal cyclists, and users of motorized and nonmotorized personal mobility devices, such as scooters, wheelchairs, and mobility carts.

NOTE 2: Road users are governed by local traffic laws.

4.16.2 ROAD OPERATOR

A traffic participant who provides, operates, and maintains the roadways and supporting infrastructure that enable and support the mobility needs of road users.

NOTE: Road operators may include infrastructure owner operators as public, public-private, or private sector entities that operate in accordance with applicable laws at the federal, state, and/or local level.

4.16.3 CERTIFICATE AUTHORITY

An entity that issues digital certificates for information transmitted wirelessly from one device to another that confirm authenticity of the certificate owner.

Refer to IEEE 1609.2 for an example.

4.16.4 COMMUNICATIONS SERVICE PROVIDER (CSP)

A traffic participant who provides and maintains the hardware and software necessary to support secure, low-latency M2M communications between and among traffic participants.

NOTE: CSPs may include public, public-private, or private sector entities that operate in accordance with applicable laws at the federal, state, and/or local level.

5.   CDA TAXONOMY

The terms defined in Section 4 describe four discrete and mutually exclusive CDA cooperation classes (i.e., status-sharing, intent-sharing, agreement-seeking, and prescriptive). Section 4 also describes two discrete levels of CDA Feature functionality enhancement (i.e., supporting and enabling). This section describes relationships between the classes and within the context of the transportation system more broadly. Qualifications that are important for properly identifying and discussing classes of CDA are presented.

5.1   Aspects of Functionality Related to CDA

CDA relates to the functionality of many types of traffic participants within the transportation system, including road users (e.g., vehicles using driving automation systems) and road operators (e.g., infrastructure owner operators managing signalized intersections and temporary traffic patterns). Figure 2 shows the relationship between CDA and the functionality of CDA device agents in the transportation network. Functionality can be described in many ways, and one of those ways is to use a generic reference architecture that includes situational awareness, planning, and action elements. It should be noted that these constructs are non-normative and may not be representative of all technology implementations, but still may serve as a helpful way to describe functionality in the context of CDA. Situational awareness may include sensor signal processing, object classification, world modeling, prediction, and other forms of knowledge. Planning may include behavior generation and value judgement. Action may include vehicle motion control and state changes (e.g., of signals and dynamic speed limits). While CDA cooperation classes generally align to these three elements of control, each class of cooperation can influence all aspects of functionality.
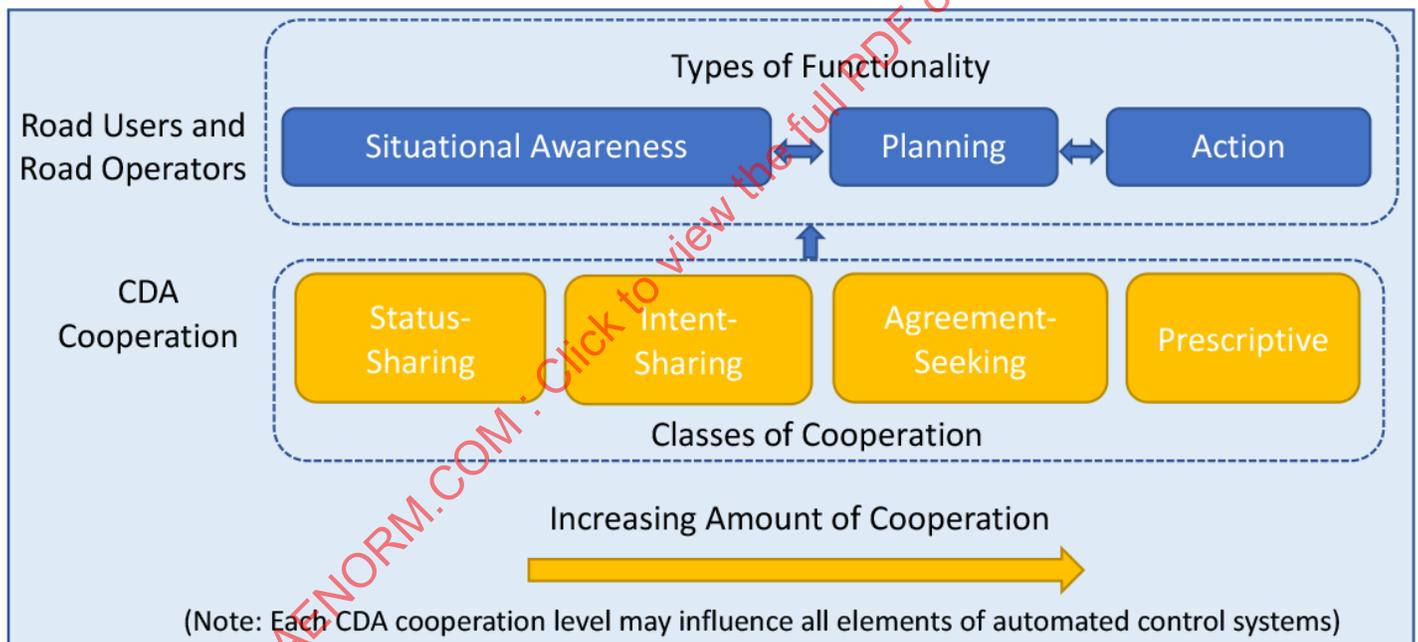

Figure 2 - Relation of CDA and traffic participants' functionality
adapted from NIST 4D-RCS reference architecture (refer to Albus et al., 2002)

The following section describes examples of functionality for particular traffic participants within the transportation system.

5.1.1   C-ADS-Operated Vehicle DDT Performance

CDA may relate to aspects of DDT performance by a C-ADS-Operated Vehicle. Activities considered to be part of the DDT according to SAE J3016 are provided for reference below:[2]

- Monitoring the driving environment via object and event detection, recognition, classification, and response preparation (operational and tactical)

- Maneuver planning (tactical)

- Object and event response execution (operational and tactical)

- Longitudinal vehicle motion control via acceleration and deceleration (operational)

- Lateral vehicle motion control via steering (operational)

- Enhancing conspicuity via lighting, signaling, and gesturing, etc. (tactical)

5.1.2   Cooperative Traffic Operations

CDA may relate to aspects of traffic operations, both by collecting and sharing information and by improving management practices. Some examples of aspects of traffic operations that may relate to CDA include:

- Detecting and providing information about road and ambient weather

- Determining and providing information about signal phase and timing

- Determining and providing information about dynamic speed limits

- Implementing ramp metering

- Emergency response management

- Detecting and providing information on traffic conditions

- Implementing temporary traffic patterns (e.g., work zones, incident management)

5.2   Classes of CDA Cooperation and Levels of Automation

The nature of cooperation differs based on the level of driving automation. The levels of driving automation describe varying roles of a human driver (if any) and a driving automation system, as described in SAE J3016. Table 1 describes the relationship between cooperation and automation. For driver support features (SAE driving automation Levels 1 and 2), only limited cooperation may be achieved based on the definition of Levels 1 and 2, as defined in SAE J3016 and neither Level 1 nor Level 2 is capable of performing complete object and event detection and response. Instead, they rely on the human driver to do at least some of these functions, as well as supervise feature performance in real time, correcting vehicle longitudinal or lateral motion control as needed. Because the driver is fully in the control loop while Level 1 and Level 2 driving automation features are engaged, careful consideration of potential human factors issues should be made if such vehicles are to automatically alter their behavior in response to M2M information (to which the driver is not privy) provided by a CDA device, as doing so could startle the driver or otherwise induce unwanted behaviors. Vehicles equipped with engaged Level 1 and 2 driving automation features can support CDA Features by sharing messages such as BSMs and/or perception information with other CDA-enabled traffic participants. For C-ADS (Levels 3 through 5), more substantial cooperation may be achieved, as the C-ADS performs the complete DDT, within its ODD, and need not be concerned with the human factors issues that prevail when a human remains in the driving control loop.

---

[2] SAE J3016 indicates that the listed activities are not exhaustive.

NOTE: At Level 0 (no driving automation), CDA Feature participation is not possible due to the lack of a driving automation system feature and CDA device capable of receiving and automatically acting upon an M2M CDA message. Nevertheless, the same wireless transmission (e.g., BSM) that supports a CDA Feature on a vehicle equipped with engaged Level 1 through 5 driving automation as Class A status sharing can also support a Level 0 vehicle as a V2X warning message to a driver.

Table 1 - Relationship between classes of CDA cooperation and levels of automation

		SAE Driving Automation Levels					
		No Automation	Driving Automation System		Automated Driving System (ADS)		
		Level 0 *No Driving Automation (human does all driving)*	**Level 1** *Driver Assistance (longitudinal OR lateral vehicle motion control)*	**Level 2** *Partial Driving Automation (longitudinal AND lateral vehicle motion control)*	**Level 3** *Conditional Driving Automation*	**Level 4** *High Driving Automation*	**Level 5** *Full Driving Automation*
CDA Cooperation Classes	**No cooperative automation**	(e.g., Signage, TCD)	Relies on driver to complete the DDT and to supervise feature performance in real time		Relies on ADS to perform complete DDT under defined conditions (fallback condition performance varies between levels)		
	Class A: Status-sharing *Here I am and what I see*	(e.g., Brake Lights, Traffic Signal)	Limited cooperation: Human is driving and must supervise CDA features (and may intervene at any time), and sensing capabilities may be limited compared to C-ADS		C-ADS has full authority to decide actions Improved C-ADS situational awareness beyond on-board sensing capabilities and increased awareness of C-ADS state by surrounding traffic participants		
	Class B: Intent-sharing *This is what I plan to do*	(e.g., Turn Signal, Merge)	Limited cooperation (both longitudinal AND lateral intent that may be overridden by human)		C-ADS has full authority to decide actions Improved C-ADS situational awareness through increased prediction reliability, and increased awareness of C-ADS plans by surrounding traffic participants		
	Class C: Agreement-seeking *Let's do this together*	(e.g., Hand Signals, Merge)	N/A	N/A	C-ADS has full authority to decide actions Improved ability of C-ADS and transportation system to attain mutual goals by accepting or suggesting actions in coordination with surrounding traffic participants		
	Class D: Prescriptive *I will do as directed*	(e.g., Hand Signals, Lane Assignment by Officials)	N/A	N/A	C-ADS has full authority to decide actions, except for very specific circumstances in which it is designed to accept and adhere to prescriptive communications		

CDA devices within a transportation network may be described by the class of CDA cooperation that they support or enable. The following two driving automation Level-based examples are illustrative:

EXAMPLE 1: A subject vehicle (SV) equipped with an engaged Level 1 adaptive cruise control (ACC) feature, as well as a CDA device that enables the ACC to receive and automatically execute longitudinal vehicle control commands, receives a CDA status-sharing message from a principal other vehicle (POV). At that moment, the SV's sensor system is occluded from detecting the presence of a pedestrian crossing in front of the POV and about to enter the path of the SV. The Class A status-sharing message sent by the POV to the SV causes the ACC to command hard braking in order to automatically prevent the SV from striking the occluded pedestrian. Note that if the SV were not also equipped with a CDA device, it could still receive a V2X warning message from a POV that hard braking is needed, but in that case, avoiding a collision with the occluded pedestrian would rely only on the human driver. The advantage of CDA is that it removes the latency associated human reaction time.

EXAMPLE 2: A C-ADS-Operated Vehicle operating at Level 4 automation and capable of utilizing agreement-seeking CDA cooperation engages in coordinated planning with other CDA devices operating in its vicinity to coordinate merging as a lane terminates. Similarly, a CDA-I device hosted by a traffic signal and capable of transmitting SPaT information (i.e., engaging in status-sharing and intent-sharing cooperation) may be described as participating in Class A and B CDA Features.

NOTE: At Level 0 (no driving automation), CDA Feature participation is not possible due to the lack of a driving automation system feature and CDA device capable of receiving and automatically acting upon an M2M CDA message. Nevertheless, the same wireless transmission (e.g., BSM) that supports a CDA Feature on a vehicle equipped with engaged Level 1 through 5 driving automation as Class A status sharing can also support a Level 0 vehicle to generate a V2X-based warning message to a driver.

5.3   Degree of CDA Feature Functionality Enhancement

The degree of improved functionality resulting from CDA Features can be described as a comparison to a baseline (i.e., without CDA) state. Table 2 describes the supporting and enabling levels of CDA Feature functionality enhancement in relation to the CDA cooperation classes. In Supporting CDA Features, capability is enhanced, such as by improving the level of accuracy and reliability of situational awareness. As the degree of functionality enhancement moves from supporting to enabling, CDA overcomes operating limitations, such as line of sight, field of view, and the ability to directly coordinate specific decision-making and control processes with other traffic participants, thus realizing benefits from CDA Feature participation that would be unachievable without it. Enabling CDA Features may allow expanded ODDs and detect objects that would otherwise be occluded. These supporting and enabling enhancements to automated driving are dependent on the development and widespread application of CDA devices with very high reliability and low latency.

Table 2 - Relationship between CDA cooperation classes
and CDA Feature functionality enhancement

		CDA Feature Degree of Functionality Enhancement	
		Supporting	Enabling
CDA Cooperation Class	**Class A: Status-sharing** *Here I am and what I see*	Enhanced functionality: Localization, world modeling, perception of surrounding objects	New function: Anticipate lane drop, see occluded object, expand ODD
	Class B: Intent-sharing *This is what I plan to do*	Enhanced functionality: e.g., higher fidelity mapping of future states	New function: Predictive intersection arrival and departure, lane change
	Class C: Agreement-seeking *Let's do this together*	N/A	New function: Coordinated intersection arrival and departure, coordinated merge, join platoon
	Class D: Prescriptive *I will do as directed*	N/A	New function: Traffic authorities can direct operations and management to improve safety and operations
			New function: Vehicle directed remotely by fleet operations center to resolve operation issue or achieve safe state in the event of incident occurrence

6.   CONSIDERATIONS FOR CDA IN PRACTICE

There are practical considerations for the development and deployment of CDA Features that may be of interest to practitioners, policy makers, and the general traveling public. This section describes characteristics of CDA communications and considerations for application of the taxonomy in practice.

6.1   Characteristics of CDA Communications

For CDA devices to effectively perform the desired CDA Feature functionality, CDA communications may need to consider certain performance characteristics. This section describes a non-exhaustive set of characteristics that may be considered important. Each CDA Feature may only need to consider a subset of these characteristics. The description of these characteristics is not meant to serve as a specification but may be useful in developing specifications.

6.1.1   Sample CDA information Content

Examples of the information types that may be exchanged, and whether that information applies to vehicles, infrastructure, or other entities, are provided below. While not addressed in this document, harmonized data exchange may be achieved through developing data definitions that are traceable, consistent, accurate, clear, complete, and concise.

The following sample information content descriptions are not intended to be prescriptive. Rather, information content is expected to reflect the specific goals of one or more CDA Features, as applicable. It should also be noted that information content will be subject to applicable federal, state, and local laws governing privacy and security, which may disallow certain information content and/or restrict the manner in which it is retained and used.

a.   Status-sharing

   1.   Object

      i.   Object classification (e.g., vehicle, pedestrian, pedal cyclist) and attributes (e.g., conventional vehicle versus C-ADS-Operated Vehicle, acceleration capabilities, vehicle classification [FHWA Classes 1 to 13], vehicle dimension, signal arrival information, number of vehicle occupants)

      ii.   Object pose (e.g., position, velocity, acceleration)

      iii.   Indicators (e.g., turn signal, headlights) and braking status (applied/not applied, braking force)

   2.   Traffic participants and environment

      i.   Infrastructure state, ambient weather, and road surface conditions

         a)   For example, friction, humidity, dew point, temperature of air, and road surface

      ii.   Traffic density, speed, or volume

      iii.   Events (e.g., signal status, traffic incident, construction)

b.   Intent-sharing

   1.   C-ADS-Operated Vehicle's intent

      i.   Predicted future state (e.g., kinematic state, projected path including turns)

      ii.   Maneuvers (e.g., lane change)

2. Other traffic participants' intent

    i. Predicted future state (e.g., kinematic state, projected path)

    ii. Maneuvers (e.g., lane change)

    iii. Signal timing

3. Perception of intention

    i. Turn signal of non-CDA device-equipped vehicle

c. Agreement-seeking (Note: only applicable to vehicular road users equipped with C-ADS)

    1. Request: Proposed actions of relevant traffic participants (e.g., vehicle maneuvers, signal timing)

    2. Response: Acceptance of proposed actions, rejection of proposed actions, or alternative proposed action

d. Prescriptive (note: only applicable to vehicular road users equipped with C-ADS)

    1. Vehicle motion control, including longitudinal and/or lateral control (maneuver-based or sustained)

    2. Traffic rules (e.g., speed limits, lane configuration)

    3. Traffic control device state (e.g., signal phase)

    4. Evacuation orders

6.1.2 Information Flows

Information flows may entail a vehicle sharing status information with other vehicles, or information sharing may be reciprocal. The communications systems used to share information are outside the scope of this document, but some examples include V2X and cellular.

The directionality of information flows is illustrated later in this document for some example use cases (see Section 7).

6.1.3 Transmission Range

Transmission range may include considerations for the physical distance over which M2M communications are exchanged.

6.1.4 [Information] Privacy

Information privacy may include considerations relating to an individual's ability to determine for themselves when, how, and for what purpose their personal information is handled by others. Some systems such as V2X communications may inherently support pseudonymity.

6.1.5 [Information] Security

Information security may include considerations promoting the confidentiality, integrity, and availability of public and private information, systems, and networks with the goal of protecting individual rights and privacy, economic interests, and national security (refer to Kosseff, 2018). Security may be described in terms of processes or measures taken to safeguard data, such as signing, encryption, tokenization, and key management.

6.1.6 [Cooperation] Latency

Cooperation latency may include considerations for the time delay from an event occurrence to the desired cooperative outcome. The lower the latency, the faster the CDA outcome may be achieved. For example, in agreement seeking, there may be latency associated with the time it takes for vehicles to respond to a request.

6.1.7　[Information] Quality

Information quality may include considerations for the fitness of use. This can include dimensions of availability, relevance, accuracy, credibility, timeliness, accessibility, interpretability, coherence, and cost-efficiency (refer to OECD 2017).

7.　EXAMPLES OF CDA FEATURES

In order to demonstrate how the CDA taxonomy may be applied in practice, this section provides examples of CDA Features. It discusses CDA devices and CDA device agents, classes of cooperation and functionality, and characteristics of CDA. The feature names used in this section are non-normative (i.e., implementations may use different naming conventions). Additional examples can be found through the Federal Highway Administration's (FHWA's) CARMA[SM] Program (refer to CARMA reference, slide 17) that has identified CDA Features designed to improve transportation system safety, efficiency, and reliability through a variety of Transportation Systems Management and Operations (TSMO) strategies.

7.1　CDA Features Relating to Cooperative Perception

Cooperative perception describes the sharing of information about nearby objects in the environment. Traffic participants may be concerned with many different relevant objects within the driving environment, such as vehicles, pedestrians, traffic control devices (e.g., signals and signage), curbs, and lane markings. Many types of information may be associated with an object, such as location, trajectory, classification, and other characteristics. Information about these characteristics can improve transportation safety and/or efficiency through improved situational awareness. For example, C-ADS-Operated Vehicles may use this information to improve object and event detection and response accuracy, reliability, line of sight, and field-of-view. Road operators may use this information to improve maneuvering throughput, facilitate response and maintenance operations, and support infrastructure planning. For object tracking features, accuracy, security, and privacy can be important considerations if the CDA Feature is to effectively perform the desired functionality (e.g., refer to use cases in the 5G-PPP 2017 technical report). Another similar example would be an event tracking feature that shares changes in the state of the nearby environment, such as traffic signal phase changes.

An example is described in Table 3 and Figure 3, in which two C-ADS-Operated Vehicles exchange information about a pedestrian's location in order to improve situational awareness.

Table 3 - Examples of cooperative perception CDA Features

Feature	Class of CDA	CDA Information Flow	Information Exchanged	Level of Functionality
Perception sharing: C-ADS-Operated Vehicle 1 shares pedestrian location and classification with C-ADS-Operated Vehicle 2	A. Status-sharing	One-way: C-ADS-Operated Vehicle 1 → C-ADS-Operated Vehicle 2	Object geospatial location, and classification ("pedestrian")	Supporting: C-ADS-Operated Vehicle 2 can sense the pedestrian, and uses the information to improve reliability and accuracy of pedestrian location and classification
				Enabling: Pedestrian was occluded from C-ADS-Operated Vehicle 2 field of view (e.g., by C-ADS-Operated Vehicle 1), and now C-ADS-Operated Vehicle 2 is aware of pedestrian