SAE INTERNATIONAL

SURFACE VEHICLE INFORMATION REPORT

J3216™ **MAY2020**

Issued 2020-05

Taxonomy and Definitions for Terms Related to Cooperative Driving Automation for On-Road Motor Vehicles

RATIONALE

Cooperative driving automation technologies enable mobility applications that are not achievable by individual automated driving system (ADS)-operated vehicles operating independently of each other. These technologies do so by sharing information that can be used to increase safety, efficiency, and reliability of the transportation system, and that may serve to accelerate the deployment of driving automation in on-road motor vehicles. Driving automation and connectivity present opportunities to deploy multiple cooperative automation strategies, but successful deployment of multiple cooperative automation strategies depends on coordination among diverse stakeholders. These include road operators, intelligent transportation system (ITS) technology providers, ADS and ADS-equipped vehicle manufacturers and suppliers, as well as ADS-dedicated vehicle (ADS-DV) fleet operators. These public and private sector stakeholders are preparing for and deploying different use cases at different temporal and spatial scales. These use cases may implement vehicle strategies, such as speed harmonization and/or transportation systems management and operations (TSMO) strategies, e.g., basic travel, traffic incident management, weather management, and workzone management data sharing. The United States Department of Transportation (U.S. DOT) highlighed the importance of cooperative situational awareness standards in its guideline document "Automated Vehicles 3.0: Preparing for the Future of Transportation."

To develop these strategies, stakeholders are engaging each other and would benefit from a common language and organization of complex technology concepts. Standardizing terms and definitions for cooperative automation and its components serves several purposes, including:

1. Clarifying the types of information to be exchanged during cooperative automation operations.
2. Clarifying cooperation capabilities (status sharing, intent sharing, agreement seeking, prescriptive) that may be required to enable cooperative automation.
3. Answering questions of scope when it comes to developing laws, policies, regulations, and standards.
4. Providing a useful framework for cooperative automation standards, specifications, technical requirements, and open-source platform development.
5. Providing clarity and stability in communications on the topic of cooperative automation, as well as a useful short-hand that saves considerable time and effort.
6. Providing a foundation and reference for future standards.
7. Reflecting current industry practice and preserving prior art to the extent practicable.

TO PLACE A DOCUMENT ORDER: **Tel: 877-606-7323 (inside USA and Canada)**
Tel: +1 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
SAE WEB ADDRESS: **http://www.sae.org**

For more information on this standard, visit
https://www.sae.org/standards/content/J3216_202005

1. SCOPE

This document describes machine-to-machine (M2M) communication to enable cooperation between two or more participating entities or communication devices possessed or controlled by those entities. The cooperation supports or enables performance of the dynamic driving task (DDT) for a subject vehicle with driving automation feature(s) engaged. Other participants may include other vehicles with driving automation feature(s) engaged, shared road users (e.g., drivers of manually operated vehicles or pedestrians or cyclists carrying personal devices), or road operators (e.g., those who maintain or operate traffic signals or workzones).

Cooperative driving automation (CDA) aims to improve the safety and flow of traffic and/or facilitate road operations by supporting the 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 application. The needs may be expressed in terms of performance characteristics, such as latency, transmission mode (e.g., one-way, two-way), range, privacy and security, and information content and quality. There are several potential technologies for communicating information between the subject vehicle and other participants.

This document focuses on application-oriented functionality and does not imply the need for or require any specific functionality associated with communications protocols or the open systems interconnection model layers in a protocol stack. This document addresses the operational and tactical timescales of dynamic driving on ADS-operated vehicles, and excludes strategic functions such as trip scheduling and selection of destinations and waypoints. This information report is intended to facilitate communication and awareness for the design and anticipated development and validation of cooperative driving automation.

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 J2735 Dedicated Short Range Communications (DSRC) 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 J3016 Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles

SAE J3063 Active Safety Systems Terms and Definitions

2.1.2 Other Publications

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

Albus et. al., “A Reference Model Architecture for Intelligent Unmanned Vehicle Systems, Version 2.0,” Prepared for the Army Research Laboratory Demo III Program, (2002).

“Automotive Vertical Sector,” 5G-PPP, White Paper, 2015.

Barickman, F., “Automated Vehicle Research,” National Highway Traffic Safety Administration, (2016). https://system-safety.org/issc2016/P04a_Vernacchia_Automation.pdf.

Kosseff, J., “Defining Cybersecurity Law,” 103 Iowa Law Review 985 (2018).

Lochrane, Taylor. “Transforming the Transportation Industry with Cooperative Automation Research Mobility Applications (CARMA),” Dec. 2018.
https://transops.s3.amazonaws.com/uploaded_files/NOCoE%20CARMA%20Webinar%20Slides.pdf.

OECD Handbook for Internationally Comparative Education Statistics, 2017, Chapter 6.

Office of the Victorian Information Commission, https://ovic.vic.gov.au/privacy/what-is-privacy/.

U.S. DOT, “DSRC Report to Congress,” 2015, Chapter 2.

U.S. DOT, “Preparing for the Future of Transportation: Automated Vehicle 3.0 (AV 3.0),” 2018, 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. DOT, “Ensuring American Leadership in Automatede Vehicle Technologies: Automated Vehicles 4.0 (AV 4.0),” 2020.
https://www.transportation.gov/sites/dot.gov/files/2020-02/EnsuringAmericanLeadershipAVTech4.pdf.

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

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)

The hardware and software that are collectively capable of performing the entire 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. (For up-to-date definitions, notes, and examples, refer to the latest version of SAE J3016.)

4.2 ADS-DEDICATED VEHICLE (ADS-DV)

A vehicle designed to be operated exclusively by a Level 4 or 5 ADS for all trips within its given ODD limitations (if any). (For up-to-date definitions, notes, and examples, refer to the latest version of SAE J3016.)

4.3 COOPERATIVE DRIVING AUTOMATION (CDA)

Automation that uses 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 enhacing performance of the DDT for a vehicle with driving automation feature(s) engaged.

NOTE 1: For C-ADS-equipped vehicles (see 4.3.1) engaged in cooperative automation, 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 2: For road operators engaged in cooperative automation, 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).

4.3.1 COOPERATIVE AUTOMATED DRIVING SYSTEM (C-ADS)

An ADS capable of utilizing CDA.

4.3.1.1 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.)

4.3.2 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.)

4.4 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-equipped vehicle in any given situation depends upon the type of message provided (see 4.4.1 through 4.4.4), as well as other information used by the C-ADS-equipped vehicle(s).

4.4.1 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 enhance an entity’s situational awareness.

NOTE 3: CDA devices that do not have direct control over the actions of the CDA device agent, e.g., pedestrians or conventional vehicles in which a human directly controls actions, may engage in status-sharing cooperation.

EXAMPLE 1: A C-ADS-equipped vehicle shares its current velocity and the velocity of the vehicle immediately in front with nearby vehicles. A C-ADS-equipped vehicle behind the status-sharing vehicle adjusts its speed to improve traffic flow and safety.

EXAMPLE 2: 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-equipped 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.

4.4.2 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. 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 2: Intent-sharing cooperation may be used to augment prediction of future states to enhance models of the planned future actions of the sending entity.

NOTE 3: Intent-sharing cooperation may augment status-sharing cooperation by providing information that relates to a future state (rather than just the current state) of a sending entity.

NOTE 4: In some cases, intent information may be shared without M2M communication (e.g., turn signals), but in many cases (e.g., occlusion of tail lights), this information could not otherwise be determined at all or as soon by a receiving entity that is not participating in CDA. These non-CDA forms of intent sharing (e.g., turn signals, human gestures, etc.) are beyond the scope of this document.

NOTE 5: CDA devices that do not have direct control over the actions of the CDA device agent, e.g., pedestrians or conventional vehicles in which a human directly controls actions, may engage in intent-sharing communication.

EXAMPLE 1: A C-ADS-equipped vehicle using a Level 3 automation highway feature acts as the sending entity to share a planned lane change with proximal traffic participants to facilitate safer and more efficient traffic flow in the immediate vicinity. A proximal vehicle with a Level 4 automation highway feature acts as the receiving entity and slows down to maintain a desired longitudinal distance when the Level 3 C-ADS-equipped vehicle merges into the lane ahead.

EXAMPLE 2: Roadside equipment (RSE) at a traffic signal acting as the sending entity shares a planned signal phase change with proximal traffic participants to facilitate eco-drive functionality. A C-ADS-equipped vehicle using a Level 3 feature approaching the signal acts as the receiving entity, and uses the signal timing to adjust longitudinal vehicle motion control for enhanced safety and efficiency by avoiding sudden emergency maneuvers.

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

A sequence of collaborative messages among specific CDA devices intended to influence local planning of specific DDT-related actions. ("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 provided via M2M communication, which may originate from any nearby traffic participant.

NOTE 2: Agreement-seeking cooperation includes an interactive exchange of messages 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.

NOTE 3: Agreement-seeking cooperation may utilize status-sharing and intent sharing cooperation.

NOTE 4: This document does not consider planning for CDA devices that do not have direct control over the actions of the CDA device agent, e.g., pedestrians or conventional vehicles and driver support features in which a human directly controls actions, instead focusing on planning for systems with driving automation.

NOTE 5: Agreement-seeking cooperation includes proposing plans for other traffic participants (i.e., "What I want you to do"). In contrast, intent-sharing includes only sharing a plan for the sending entity (i.e., "What I plan to do").

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

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

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

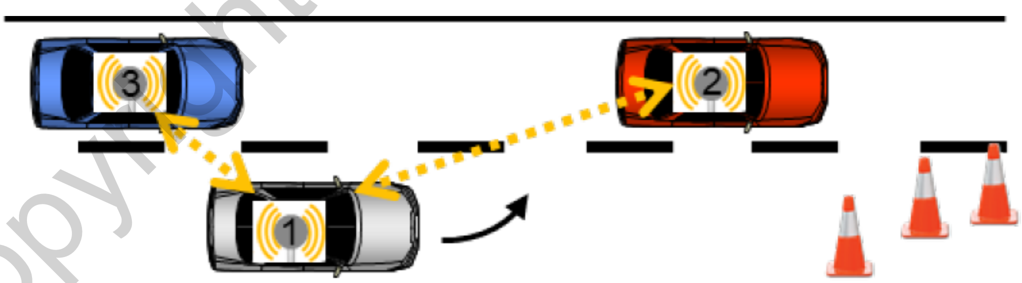

Figure 1 - Cooperative merging example

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-equipped vehicles stopped at the intersection receive the SPaT information, and the second-in-line vehicle requests to engage in agreement-seeking cooperation with the first-in-line vehicle; (3) the first-in-line vehicle is a C-ADS-equipped and agrees to engage in agreement-seeking cooperation; (4) the second-in-line vehicle proposes an acceleration and final velocity for departing the intersection based on SPaT information; (5) the first-in-line vehicle agrees to the proposed acceleration and final velocity; (6) both vehicles conduct competent operations while following the agreed-upon acceleration and final velocity resulting in a safer and more efficient intersection navigation and more efficient departure and navigation of the intersection.

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

4.4.4 PRESCRIPTIVE COOPERATION (CLASS D)

The direction of specific action(s) to 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 prescribing CDA device agent(s) and adhered to by a receiving CDA device agent(s). ("I will do as directed.")

NOTE 1: CDA devices that do not have control over the actions of their corresponding CDA Agents, e.g., pedestrians or conventional vehicles and driver support features in which a human directly controls actions, cannot participate in prescriptive cooperation-based CDA features.

NOTE 2: Prescriptive cooperation does not require the willingness of the affected entities to cooperate. It relies on a pre-existing understanding between parties to adhere to commands, such as a specific aspect of DDT performance, under particular circumstances.

NOTE 3: Prescriptive cooperation may be performed by transportation authorities and/or fleet operations centers communicating with fleet vehicles under their control.

NOTE 4: Transportation authorities may have the ability to direct prescriptive cooperation to any relevant traffic participants.

NOTE 5: 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-equipped vehicles with CDA devices 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-equipped 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 room.

4.5 CDA DEVICE

A device equipped with requisite M2M communication technology that is used by traffic participants to perform CDA features.

4.6 CDA DEVICE AGENT

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

4.7 CDA FEATURE

The design-specific functionality supported or enabled by M2M cooperation among CDA devices communicating with a C-ADS engaging in CDA.

NOTE 1: A given CDA device agent may employ multiple CDA features simultaneously, where each feature is associated with a particular data exchange, CDA device(s), and usage specification.

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

4.7.1 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-equipped vehicle detects a pedestrian in a crosswalk and shares object classification and path prediction information with a second approaching C-ADS-equipped 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-equipped vehicle conducts CDA with a cooperative intersection device, receiving SPaT information, facilitating proactively planning and optimization of approach and departure by the vehicle to reduce congestion and travel time and enhance efficiency.

4.7.2 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: Unlike supporting CDA feature, enabling CDA features result in a different outcome (e.g., detect occluded object, achieve target lane position, expand ODD, etc.).

EXAMPLE 1: A C-ADS-equipped vehicle detects a pedestrian in a crosswalk and shares information with a second approaching C-ADS-equipped vehicle about the location of a pedestrian in a crosswalk, where the second vehicle may not have the capability to otherwise detect the pedestrian, due to line-of-sight blockage by another vehicle on the road. 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-equipped vehicles with SPaT information allowing nearby C-ADS-equipped vehicles to coordinate their departure timing and velocity trajectory for enhanced safety and efficiency.

EXAMPLE 3: A CDA feature enables closely coordinated 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-equipped vehicle uses M2M communication to request a desired lane position and maneuvers from nearby C-ADS-equipped 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.

4.8 DRIVING AUTOMATION

The performance by hardware/software systems of part or all of the DDT on a sustained basis. (For up-to-date definitions, notes, and examples, refer to the latest version of SAE J3016.)

4.9 DRIVING AUTOMATION SYSTEM 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 Levels 1 to 5 driving automation. (For up-to-date definitions, notes, and examples, refer to the latest version of SAE J3016.)

4.10 DYNAMIC DRIVING TASK (DDT)

All of the real-time operational and tactical functions required to operate a vehicle in on-road traffic, excluding the strategic functions such as trip scheduling and selection of destinations and waypoints. (For up-to-date definitions, notes, and examples, refer to the latest version of SAE J3016.)

4.11 OPERATIONAL DESIGN DOMAIN (ODD)

Operating conditions under which a given 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. (For up-to-date definitions, notes, and examples, refer to the latest version of SAE J3016.)

4.12 [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.

4.13 TRAFFIC PARTICIPANT

Entities whose actions influence travel in the transportation environment, which may include road users engaged in travel upon or across publicly accessible roadways and road operators.

4.13.1 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, pedalcyclists, and users of motorized and non-motorized personal mobility devices, such as scooters, wheelchairs, and mobility carts.

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

4.13.2 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.

4.13.3 CERTIFICATE AUTHORITY

An entity that issues digital certificates that confirm authenticity of the certificate owner.

4.13.4 COMMUNICATIONS SERVICE PROVIDER (CSP)

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

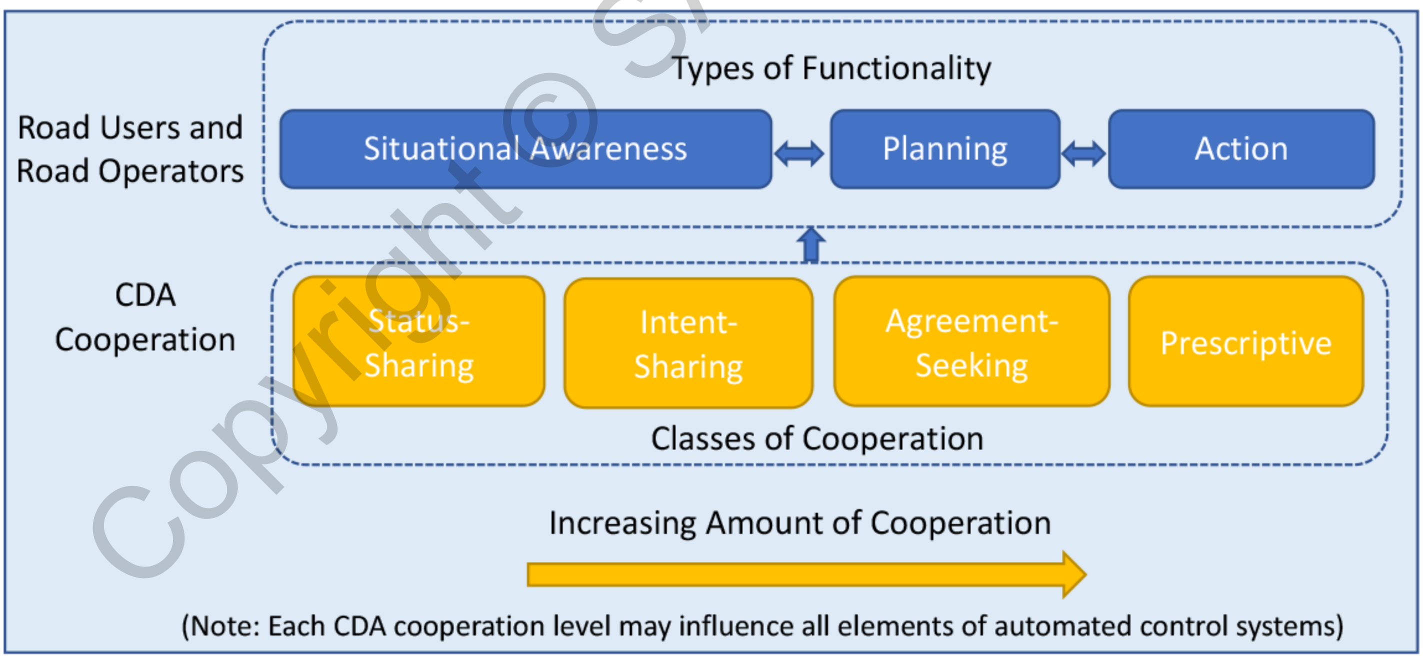

Figure 2 - Relation of CDA and transportation system agents' function adapted from NIST 4D-RCS reference architecture (Albus et. al. 2002)

The following section describes examples of functionality for particular CDA device agents within the transportation system.

5.1.1 Cooperative ADS DDT Performance

CDA may relate to aspects of DDT performance by a C-ADS-equipped vehicle. Activities considered to be part of the DDT according to SAE J3016 are provided for reference below[1]:

- 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., workzones, 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 due to the fact that the automation does not perform complete object and event detection and response, relying on the human driver to do at least some of these functions, as well as supervise feature performance in real time. For C-ADS (Levels 3 through 5), more substantial cooperation may be achieved, where the C-ADS performs the complete DDT under defined conditions.

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

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 road users and road operators		
	Class B: Intent-sharing *This is what I plan to do*	(e.g., Turn Signal, Merge)	Limited cooperation (only longitudinal OR lateral intent that may be overridden by human)	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 road users and road operators		
	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 road users and road operators		
	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 a prescriptive communication		

CDA devices within a transportation network may be described by the class of CDA cooperation that they support. For example, a C-ADS feature operating at Level 4 automation and capable of utilizing agreement-seeking CDA cooperation may be described as a Class C C-ADS feature. This entails that the C-ADS is capable of engaging in coordinated planning with other CDA devices in the transportation network. Similarly, a traffic signal CDA device capable of sharing signal phase and timing information (i.e., engaging in status-sharing and intent-sharing cooperation) may be described as Class A and B C-ADS features.

5.3 Level of CDA Feature Functionality enhancement

The level of improved functionality resulting from CDA features can be described as a comparision 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 level 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 actors. 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 Cooperation Class	CDA Feature Level of Functionality Enhancement: Supporting	CDA Feature Level of Functionality Enhancement: Enabling
Class A: Status-sharing *Here I am and what I see*	Enhanced functionality: Localization, world modeling, perception	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 communication and considerations for application of the taxonomy in practice.

6.1 Characteristics of CDA Communication

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

i. Status-sharing

1. Object

a. Object classification (e.g., vehicle, pedestrian, pedal cyclist) and attributes (e.g., C-ADS-equipped, acceleration capabilities, vehicle classification (FHWA Classes 1 to 13), vehicle dimension, signal arrival information, number of vehicle occupants)

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

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

2. Traffic participants and environment

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

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

b. Traffic density, speed, or volume

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

ii. Intent-sharing

1. C-ADS's intent

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

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

2. Other traffic participant's intent

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

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

c. Signal timing

3. Perception of intention

a. Turn signal of non-cooperative vehicle

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

1. Seeking and agreeing to engage in agreement-seeking cooperation

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

3. Acceptance of proposed actions, rejection of proposed actions, or alternative proposed action

iv. 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 Transmission Modes

Transmission modes may include considerations for the directionality and access to information in cooperative automation to determine what use cases can be enabled.

i. One-way information flow: information is transmitted by a CDA device and received by one or more other CDA devices, but no information is shared reciprocally.

ii. Two-way information flow: information is shared reciprocally between CDA devices.

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 (Office of the Victorian Information Commission, 2019).

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 (J. 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.

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 (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 (FHWA)'s CARMA℠ 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 Features Relating to Cooperative Object Tracking

Cooperative object tracking 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), 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-equipped 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 throughput, facilitate response and maintenance operations, and to 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; e.g., signal changes.

An example is descibed in Figure 3, in which two C-ADS vehicles exchange information about a pedestrian's location in order to improve situation awareness.

Table 3 - Examples of supporting and enabling cooperative object tracking features

Feature	Class of CDA	CDA Device Transmission Mode and Directionality	Information Exchanged	Level of Functionality
Object Tracking: C-ADS 1 shares pedestrian location and classification with C-ADS 2	A. Status-sharing	One-way: C-ADS 1 → C-ADS 2	Object geospatial location, and classification ("pedestrian")	Supporting: C-ADS 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 2 field of view (e.g., by C-ADS 1), and now C-ADS 2 is aware of pedestrian

NOTE: In practice, one-way transmission will typically send the message to multiple CDA devices in the vicinity.

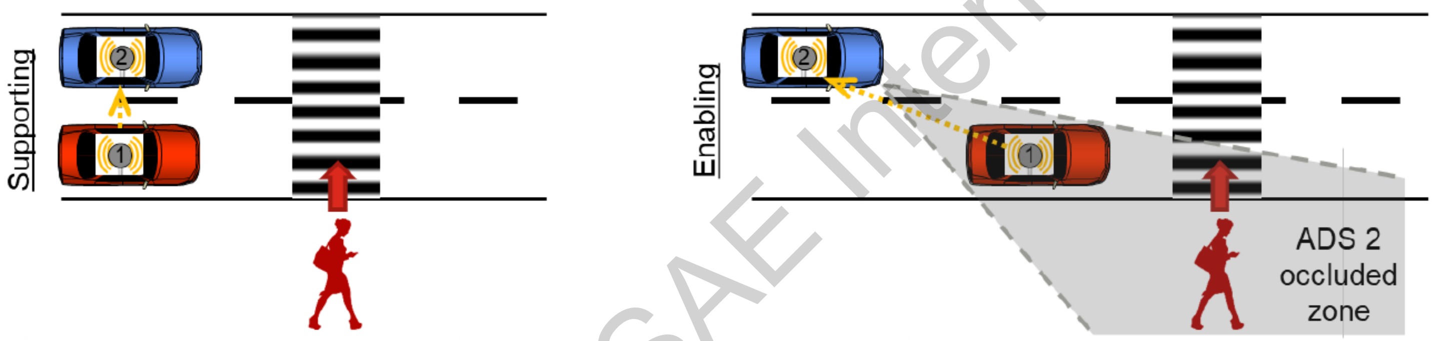

Figure 3 - Depictions of (a) supporting, and (b) enabling cooperative object tracking features

7.2 Features Relating to Cooperative Traffic Signal

Cooperative traffic signals share messages that support navigation of intersections and control of signal phase. CDA device agents may be concerned with optimizing vehicle velocity profile and coordination of movement with surrounding vehicles. Types of information that may be exchanged include signal phase and timing with roadside equipment (RSE), proposed velocity profiles, and agreement to proposed velocity profiles. CDA device agents may use this information to improve efficiency, travel times, and safety.

An example is depicted in Figures 4 and 5 showing an intersection approach and departure feature at a signalized intersection.

Table 4 - Examples of cooperative signalized intersection features

Feature	Class of CDA	CDA Device Transmission Mode and Directionality	Information Exchanged	Level of Functionality
Eco-Approach and Departure	A. Status-sharing	One-way: RSE 3 → C-ADS 1	Signal phase	Supporting: C-ADS 1 plans motion more effectively with increased reliability and look ahead distance to reduce energy consumption and emissions
Signal Priority	A. Status-sharing	One-way: C-ADS 1 → RSE 3	Vehicle location, speed, and priority status (e.g., emergency vehicles)	Enabling: Signal timing changed based on the approaching vehicle
Eco-Approach and Departure	B. Intent-sharing	One-way: RSE 3 → C-ADS 1, 2	SPaT information	Enabling: C-ADS 1, 2 plan motion based on the future signal phase information that would otherwise be unavailable
Tandem Approach and Departure	C. Agreement-seeking	Two-way: RSE 3 → C-ADS 1, 2 C-ADS 2 → C-ADS 1 C-ADS 1 → C-ADS 2	SPaT information C-ADS 2 proposes velocity profile to C-ADS 1 C-ADS 1 agrees	Enabling: C-ADS 1, 2 plan motion based on future signal phase to enable velocity optimization for both vehicles

NOTE: In practice, one-way transmission will typically send the message to multiple CDA devices in the vicinity.

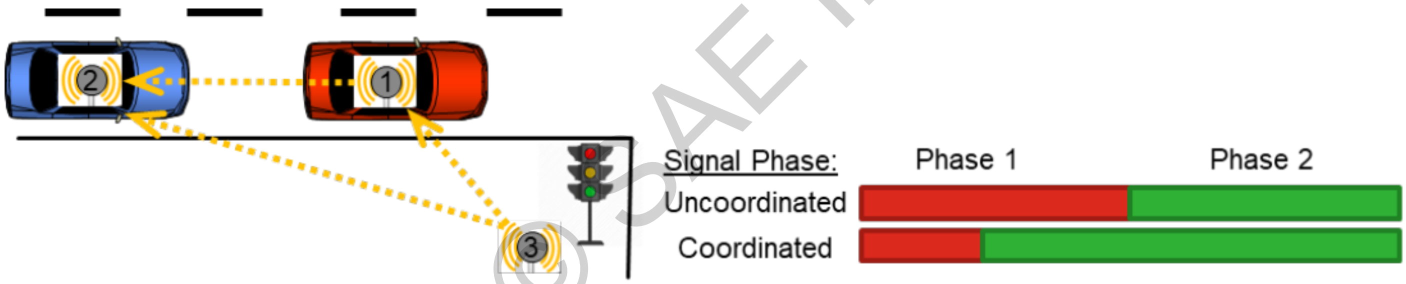

Figure 4 - Depiction of (a) cooperative signalized intersection feature, and (b) example of signal priority influence on signal phase

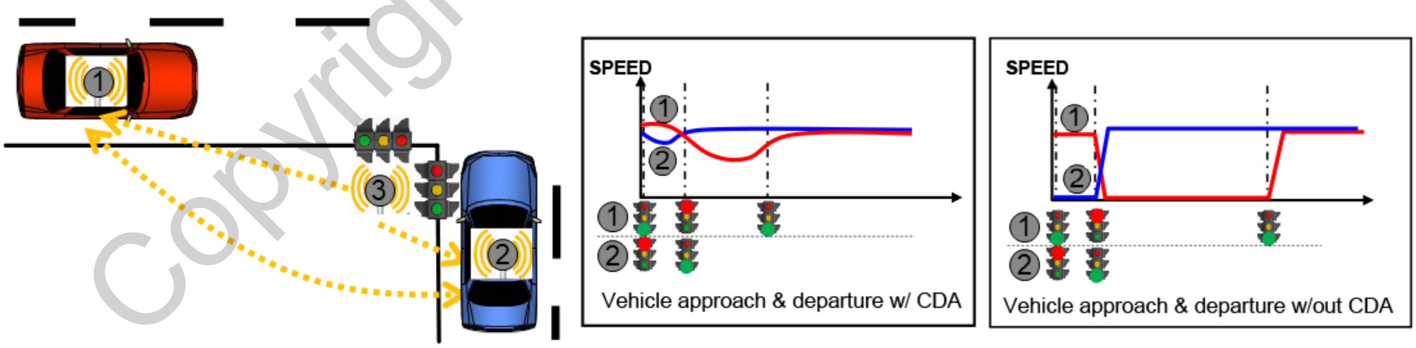

Figure 5 - Depiction of cooperative signalized intersection feature with comparison of vehicle approach and departure speed with and without CDA

7.3 Features Relating to Cooperative Lane Change

Cooperative lane changing describes sharing of one or more messages that support navigation to new lane positions. CDA features may be concerned with optimizing vehicle velocity profile and coordination of movement with surrounding vehicles. Types of information that may be exchanged include intent to merge, proposed maneuvers, and agreement to proposed maneuvers. CDA agents may use this information to improve energy efficiency and travel times.

Figure 6 shows two examples (i.e., B and C) of cooperative lane changing behavior for a temporary traffic pattern, which could include an emergency response scene or workzone with CDA-equipped RSE.

Table 5 - Examples of cooperative merging features

Feature	Class of CDA	CDA Device Transmission Mode and Directionality	Information Exchanged	Level of Functionality
Cooperative Lane Change Cooperative Merge	B. Intent-sharing	One-way: C-ADS 1 → C-ADS 3	Planned maneuver	Supporting: C-ADS 1 shares intent to merge between C-ADS 2 and 3; C-ADS 2 and 3 may or may not act on this information
	C. Agreement-seeking	Two-way: C-ADS 1 → C-ADS 3 C-ADS 3 → C-ADS 1	Proposed maneuver C-ADS 3 agrees	Enabling: C-ADS 1 shares intent to merge in front of C-ADS 3; C-ADS 3 agree to take action to allow the merge

NOTE: In practice, one-way information flow will typically send the message to multiple CDA devices in the vicinity.

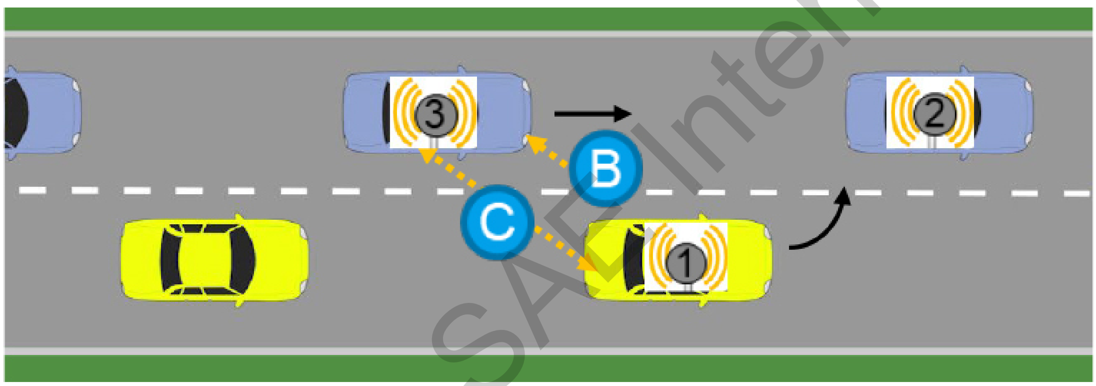

Figure 6 - Depiction of cooperative merging features

7.4 Features Relating to Cooperative Traffic Management

Cooperative traffic management describes sharing or one of more messages that support navigation of potentially challenging road segments that may differ in geometry and traffic laws from a-priori maps and make use of traffic control devices. CDA device agents may benefit from information that helps improve world models and obeyance of traffic laws. Types of information that may be exchanged include lane configuration geometry and speed limits. CDA device agents may use this information to improve situational awareness and expand their ODD.

Figure 7 shows two cooperative traffic management examples (i.e., A and D) of RSE providing status and prescriptive information for a lane closure.

Table 6 - Examples of cooperative traffic management features

Feature	Class of CDA	CDA Device Transmission Mode and Directionality	Information Exchanged	Level of Functionality
Temporary Lane Closure: RSU shares geofence and lower speed limit with road users; road users may use information to coordinate motion	A. Status-sharing	One-way: RSE 4 → C-ADS 1	Location of lane drop	Supporting: C-ADS may detect lane drop more quickly, accurately, and reliably
				Enabling: C-ADS would otherwise be unable to navigate the temporary traffic pattern
	C. Agreement-seeking	One-way: C-ADS 1 → C-ADS 2	Proposed maneuver	Enabling: C-ADS 1 shares intent to change lanes ahead of C-ADS 2; C-ADS 2 agrees to take action to allow the lane change
Dynamic Speed Limit: RSU shares geofence and lower speed limit with road users; road users may use information to coordinate motion	D. Prescriptive	One-way: RSE 5 → C-ADS 1, 2, 3, 4	New speed limit	Enabling: C-ADS directed to slow down to obey traffic law

NOTE: In practice, one-way transmission will typically send the message to multiple CDA devices in the vicinity.

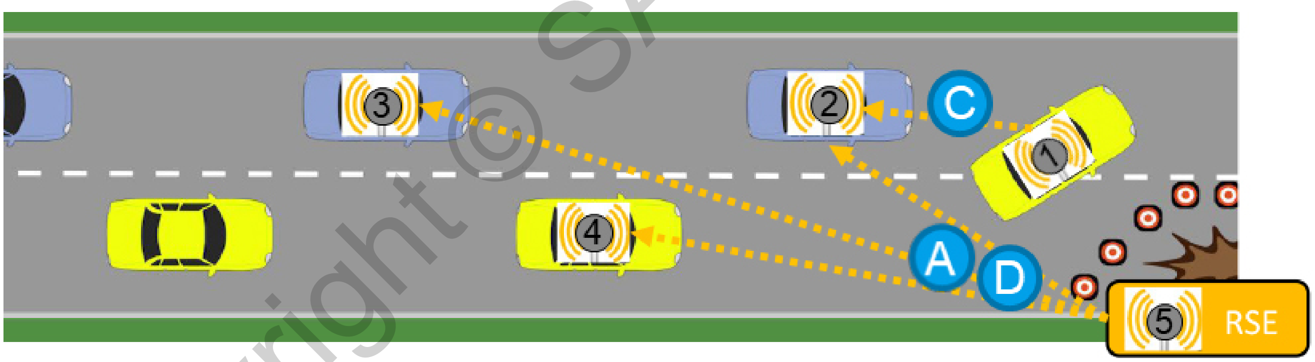

Figure 7 - Depiction of cooperative traffic management with temporary lane closure and dynamic speed limit

7.5 Features Relating to Cooperative Vehicle Following (Including Platooning)

Cooperative vehicle following describes sharing of one or more messages that support coordinating longitudinal movements of vehicles, and may also include lateral control of vehicles, such as coordinated lane changes of platoons. Types of information that may be exchanged include locations, trajectories, headways, and platooning status. CDA device agents may use this information to improve efficency, traffic flow, and safety.

Figure 8 shows an example of three different types of cooperative vehicle following features.

Table 7 - Examples of cooperative vehicle following features

Feature	Class of CDA	CDA Device Transmission Mode and Directionality	Information Exchanged	Level of Functionality
Platooning Awareness and CACC* vehicle control**	A. Status-sharing	Two-way: CDA Vehicle 1 ←→ CDA Vehicle 2, 4 CDA Vehicles 1 → CDA Vehicle 3	Platooning/CACC activation status; speed, trajectory, and location of vehicles in platoon	Supporting: Follower vehicles in platoon can follow more closely and stably than they could otherwise Supporting: CDA Vehicle 3 has additional awareness that CDA Vehicle 1 is platooning with other vehicles
Advance notice of braking maneuver	B. Intent-sharing	One-way: C-ADS 1 → C-ADS 2, 4	Planned speed reduction	Supporting: C-ADS 1 detects forward hazard that may require deceleration of platoon, enabling smoother deceleration of all vehicles
Platoon Joining	C. Agreement-seeking	Two-way: C-ADS 3 → C-ADS 1 C-ADS 1 → C-ADS 3 C-ADS 1 → C-ADS 2,4	Seeking to join platoon; allow to join platoon in the middle; inform other platooners	Enabling: C-ADS 3 can join the platoon in the middle (otherwise it would have had to join at the end)

* CACC: Cooperative Adaptive Cruise Control.

** Note example A has been defined using CDA vehicles (i.e., SAE Levels 1 to 5 automation), and the B and C examples have been defined for C-ADS (i.e., SAE Levels 3 to 5 automation).

NOTE: In practice, one-way information flow will typically be done by sending the message to multiple CDA devices in the vicinity.

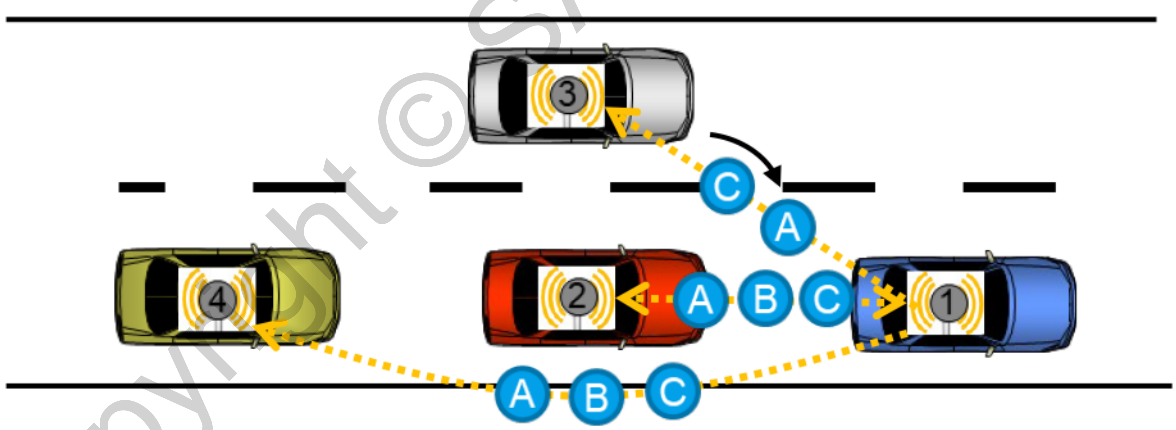

Figure 8 - Depiction of cooperative vehicle following features

8. NOTES

8.1 Revision Indicator

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

PREPARED BY THE ON-ROAD AUTOMATED DRIVING (ORAD) COMMITTEE