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Location	Incorrect Values	Corrected Values
Page 3, Table 1 note	N/A; new table note added.	Note: Table 1 was created by the project team to support the development of CDA concepts. During the publication process, SAE released a new standard: J3216, *Taxonomy and Definitions for Terms Related to Cooperative Driving Automation for On-Road Motor Vehicles* (SAE International 2020). Table 1 is similar to the defined standards; however, any references to the SAE J3216 CDA Cooperation Classes should reflect that of the newly approved industry standard.
Page 107, References	N/A; new reference added.	SAE International. (2020). *Taxonomy and Definitions for Terms Related to Cooperative Driving Automation for On-Road Motor Vehicles*, J3216-202005, SAE International, Warrendale, PA. Available online: https://www.sae.org/standards/content/j3216_202005/, last accessed February 9, 2021.

N/A = not applicable.

Detailed Concept of Operations: Transportation Systems Management and Operations/Cooperative Driving Automation Use Cases and Scenarios

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Federal Highway Administration

Research, Development, and Technology
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FOREWORD

The Federal Highway Administration's Turner-Fairbank Highway Research Center performs advanced research into several areas of transportation technology. The Office of Operations Research and Development focuses on improving operations-related technology through research, development, and testing.

This report presents a detailed concept of operations (ConOps) for the four transportation systems management and operations (TSMO) use cases—basic travel, traffic-incident management, road-weather management, and work-zone management—defined as part of the high-level ConOps for the CARMA℠ effort to define and develop a set of testable use cases that demonstrate how cooperative driving automation capabilities can be integrated with TSMO strategies. This detailed ConOps lays out the selected example situations under the Group 1 priority situations. For each priority situation, the operational needs, operational design domain, associated stakeholders, concept diagrams, information flows, triggers, and functional requirements were identified. This report is intended for all transportation stakeholders interested in CARMA and the relationship between cooperative driving automation and transportation systems management and operations strategies.

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Research and Development

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16. Abstract This report presents the detailed concept of operations (ConOps) in support of the CARMA Platform℠ sponsored by the Federal Highway Administration's Office of Operations Research and Development. The high-level ConOps focuses on four transportation systems management and operations use cases—basic travel, traffic-incident management, road-weather management, and work-zone management—and explores the framework of those relationships in greater detail. As part of the high-level ConOps, researchers identified approximately 160 different situations falling under each of the 4 use cases. This detailed ConOps identifies the selected priority situations under Group 1 priority use cases. For each priority situation, the research team identified the operational needs, operational design domain, associated stakeholders, concept diagrams, information flows, triggers, and functional requirements. Each situation includes an applicable scenario description and a user requirements traceability matrix.		
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
	NOTE: volumes greater than 1,000 L shall be shown in m^3			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	$candela/m^2$	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	2.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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LIST OF ACRONYMS

ABS	antilock braking system
ADS	automated driving system
AFAD	automated flagger assistance device
ATM	active traffic management
CDA	cooperative driving automation
ConOps	concept of operations
DOT	department of transportation
FHWA	Federal Highway Administration
ITS	intelligent transportation systems
MUTCD	*Manual on Uniform Traffic Control Devices*
NAK	negative acknowledgment
OBU	onboard unit
ODD	operational design domain
RSU	roadside units
RWIS	road weather information system
RWM	road-weather management
SPaT	signal phase and timing
TCD	traffic-control devices
TIM	traffic-incident management
TMC	Traffic Management Center
TMS	transportation management service
TSMO	transportation systems management and operations
TSP	transit signal priority
VMS	variable message sign
VSL	variable speed limit
WZM	work-zone management

CHAPTER 1. INTRODUCTION

PURPOSE

This report presents the detailed concept of operations (ConOps) in support of the CARMA Platform℠ sponsored by the Federal Highway Administration's (FHWA's) Office of Operations Research and Development. This ConOps is another step in the ongoing CARMA℠ effort to define and develop a set of testable use cases that demonstrate how cooperative driving automation (CDA) capabilities can be integrated with transportation systems management and operations (TSMO) strategies.

This report was published with the *High-Level Concept of Operations: Examination of the Relationships Between Transportation Systems Management and Operations Strategies and Cooperative Driving Automation* (FHWA-HRT-20-063), which examined the essentials in the TSMO/CDA relationship by looking at the range of traditional TSMO strategies for operating and managing transportation infrastructure and identifying those strategies expected to be impacted by the introduction of CDA technologies (FHWA 2020). The high-level ConOps focused on four sets of use cases: basic travel, traffic-incident management (TIM), road-weather management (RWM), and work-zone management (WZM). The use cases explored the framework of the TSMO/CDA relationship in greater detail and examined the actions that each entity responsible for TSMO activities (e.g., an organization operating a transportation management service [TMS]) would perform to achieve the TSMO strategy. The high-level ConOps mapped whether and how CDA will impact existing TSMO use-case activities. This mapping considered both the levels of vehicle automation and classes of vehicle cooperation.

As part of the high-level ConOps, the research team identified approximately 160 situations classified under each of the 4 identified use cases. Domain experts assisted with prioritizing these situations. Ultimately, two groups of priorities, with four situations each, were determined for initial consideration within CARMA.

This detailed ConOps identifies the selected priority situations under the Group 1 priority use cases. For each priority situation, researchers identified operational needs, operational design domain, associated stakeholders, concept diagrams, information flows, triggers, and functional requirements. Each situation includes an applicable scenario description and a user requirements traceability matrix.

The example situations presented in this document are designed to allow for building associated algorithms, integrating the algorithms into CARMA, and testing the algorithms under proving-ground or onroad conditions within the next steps of CARMA.

DOCUMENT OVERVIEW

This detailed ConOps includes the following components:

- Use cases and priority situations. Brief descriptions of the four use cases, the automated driving system (ADS) vehicle travel areas used within each use case, the situation groups, and the situations. This section also includes a brief description of the process used to determine the prioritized situations indicated as follows:
  - Basic travel prioritized situation.
  - TIM prioritized situation.
  - RWM prioritized situation.
  - WZM prioritized situation.

Each of the four prioritized situations includes the following information: operational needs, associated stakeholders, concept diagrams, situation triggers, functional requirements, and user functional requirements traceability matrix.

Short- and long-range communications are defined as follows in the context of this report:

- Short-range communications: short-distance communications, including the dedicated short-range communications suite of protocols, such as Wireless Local Area Network (WLAN) protocol, IEEE802.11p.
- Long-range communications: long-distance communications, such as 3G, 4G/LTE, 5G, or cellular vehicle-to-everything, which support wide area communication over a cellular network.

This detailed ConOps framework distinguishes between levels of vehicle automation and classes of vehicle cooperation. These Cooperation Classes are defined in table 1.

Table 1. Relationships between Automation Levels and Cooperation Classes.

Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
No cooperative automation	E.g., signage, traffic-control device	Relies on onboard sensors and driver monitoring to support limited maneuvers.	Relies on onboard sensors and driver monitoring to support limited maneuvers.	Relies only on onboard sensors for perception to support maneuvers.	Relies only on onboard sensors for perception to support maneuvers.	Relies only on onboard sensors for perception to support maneuvers.
A	E.g., brake lights, traffic signal	Combines onboard sensors with status data and driver monitoring to support limited maneuvers.	Combines onboard sensors with status data and driver monitoring to support limited maneuvers.	Combines onboard sensors with status data for improved perception to support maneuvers.	Combines onboard sensors with status data for improved perception to support maneuvers.	Combines onboard sensors with status data for improved perception to support maneuvers.
B	E.g., turn signal, merge	Supports limited coordinated maneuvers.	Supports limited coordinated maneuvers.	Shares intentions to support coordinated maneuvers.	Shares intentions to support coordinated maneuvers.	Shares intentions to support coordinated maneuvers.
C	E.g., hand signals, lane assignment	Supports limited cooperative maneuvers.	Supports limited cooperative maneuvers.	Enables direct negotiations to support cooperative maneuvers.	Enables direct negotiations to support cooperative maneuvers.	Enables direct negotiations to support cooperative maneuvers.

*Note: Table 1 was created by the project team to support the development of CDA concepts. During the publication process, SAE released a new standard: J3216, *Taxonomy and Definitions for Terms Related to Cooperative Driving Automation for On-Road Motor Vehicles* (SAE International 2020). Table 1 is similar to the defined standards; however, any references to the SAE J3216 CDA Cooperation Classes should reflect that of the newly approved industry standard.

CHAPTER 2. USE CASES AND PRIORITY SITUATIONS

TYPOLOGY

The framework concept for TSMO and TMS operations related to the CDA automation defined in the high-level ConOps accounts for the different classes of cooperation that can occur between equipped vehicles and nonequipped vehicles, roadside equipment, and TMSs. This framework design assumes that the data provided by a vehicle arrive at the TMS and data from the TMS are provided to a vehicle, regardless of the underlying communications (i.e., short or long range) and whether there are intermediate devices (i.e., roadside units) relaying data between the TMS and vehicles. The framework also considers the *Connected Vehicle Reference Information Architecture*, particularly the Vehicle Data for Traffic Operations application (USDOT 2016).

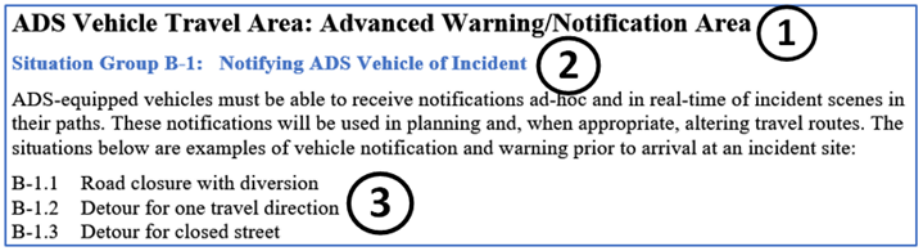
In terms of TSMO-related activities, each use case (or domain) has its own set of operational actions. These actions include activities to be performed regardless of the presence of ADS-equipped vehicles. Examples of these activities include detection, verification, notification and advisories, responses, management of work zones, and management of incidents sites.

The following sections describe the components and processes used to prioritize situations for each use case.

Transportation agencies use TSMO strategies to optimize the safety, mobility, and reliability performance of existing transportation facilities. *High-Level Concept of Operations: Examination of the Relationships Between Transportation Systems Management and Operations Strategies and Cooperative Driving Automation* (FHWA-HRT-20-063) identified 18 TSMO strategy groups totaling 90 TSMO strategies.

Each TSMO and cooperation class association defined in the High-Level ConOps (table 3 and table 4 of that document) constitutes a unique use case. The use cases highlight the impacts of CDA automation levels and cooperation classes on the TSMO strategies. Four use cases—basic travel, TIM, RWM, and WZM—were scoped for evaluation and used within the CARMA project.

Each use case included the following three layers to focus the evaluation and situation determination: (1) vehicle travel areas, (2) situation groups, and (3) example situations. The layers are illustrated in figure 1.



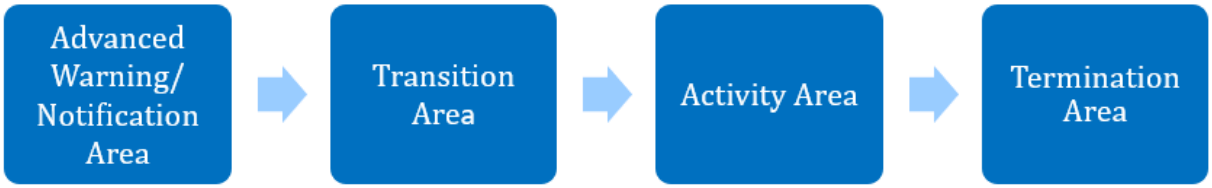
Source: FHWA.

Figure 1. Illustration. Relationship between travel areas, situation groups, and specific situations.

These layers were created separately for each use case and were subsequently used within the situation prioritization process described in the following sections.

ADS VEHICLE TRAVEL AREAS

Travel areas used in conjunction with ADS-equipped vehicles are areas that ADS-equipped general traffic vehicles, first-responder vehicles, and work vehicles typically pass through when interacting with nonrecurring roadway issues, such as traffic incidents, road weather events, and work zones. Travel areas and their sequences are identified in figure 2.



Source: FHWA.

Figure 2. Illustration. Automated Driving Systems vehicle travel areas and sequences.

In the advanced warning/notification area, the ADS-equipped vehicle is notified by the Traffic Management Center (TMC) or another ADS-equipped vehicle in advance of an event along the route for situational awareness. Key units of information transmitted from the TMC to the vehicle include what hazards may be encountered, such as work zone, incident, or blocked lanes. The TMC also notifies the ADS-equipped vehicle where the event is located, which is usually the distance to the event. The TMC can also indicate which action the vehicle should take in anticipation of the event, such as reducing speed, changing lanes, or taking a detour (Dudek et al. 2006). The source of the information may include a geofenced broadcast such as a work-zone layout or a weather situation from the infrastructure, such as a variable message sign, TMSs, and other vehicles capable of sharing information, such as general traffic and first-responder or work-zone vehicles.

The transition area is the section of the roadway in which the ADS-equipped vehicle performs the actions required to safely maneuver around the event. For example, a work zone that blocks the right lane of a four-lane highway will require a vehicle to reduce speed, detect queues, and merge into the left lane as it approaches the work-zone area. Traffic-control devices (TCDs)

(e.g., arrow boards, variable speed limit [VSL] systems, lane control systems, or human flaggers) with electronic sensors can guide the vehicles through the transition area.

The activity area is the work or incident scene in which the first-responder and worker activities are performed. The activity area may be on a shoulder, travel lane, or median and can cause reductions in roadway capacity and lane availability. An ADS-equipped vehicle needs to continuously monitor the activity area for workers, machinery, and safety equipment (e.g., cones and barrels) that may inadvertently intrude into the open travel lane.

The termination area is where the activity area ends and the roadway is back to full capacity, allowing vehicles to resume traveling at posted speed limits.

The research team investigated the ADS vehicle travel areas and evaluated them separately for each use case. The determination could have led to very different ADS vehicle travel areas but were determined to be similar for current use cases. The basic travel use cases, which are explained below, were the exception because they did not have distinct ADS vehicle travel areas. The resulting ADS vehicle travel areas for the TIM, RWM, and WZM use cases were defined according to the ADS vehicle travel areas and sequences shown in figure 2.

Situation Groups

The ADS-equipped vehicle travel areas are categorized into one or more applicable situation groups. The alphabetical part of the situation group represents the use case, and the numeric part represents the group number. For example, the first situation group under Basic Travel is A-1.

The research team defined the following situation groups to link the ADS vehicle travel areas with these groups.

Basic Travel Use Case

- Situation Group A-1: Basic travel operations for all roadway types.
- Situation Group A-2: Basic travel operations for highways.
- Situation Group A-3: Basic travel operations for arterials.

TIM Use Case

- Situation Group B-1: Notifying ADS-equipped vehicle of incident (travel area: advanced warning/notification).
- Situation Group B-2: ADS first-responder vehicles setting up incident site (travel area: transition area).
- Situation Group B-3: ADS-equipped vehicles interacting with first-responder vehicles approaching incident site (travel area: transition area).
- Situation Group B-4: ADS-equipped vehicles approaching incident site (travel area: transition area).
- Situation Group B-5: ADS-equipped vehicles interacting with traffic-control devices (travel area: transition area).

- Situation Group B-6: ADS-equipped vehicles interacting with first-responder personnel warning of incident site (travel area: transition area).
- Situation Group B-7: ADS-equipped vehicles interacting with people at or in incident site (travel area: activity area).
- Situation Group B-8: ADS-equipped vehicles interacting with incident site on side of road (travel area: activity area).
- Situation Group B-9: ADS-equipped vehicles navigating incident site with lanes blocked (travel area: activity area).
- Situation Group B-10: ADS first-responder vehicles entering, exiting, or inside incident site (travel area: activity area).
- Situation Group B-11: ADS first-responder vehicles clearing incident site (travel area: termination area).

RWN Use Case

- Situation Group C-1: Notifying ADS-equipped vehicles of upcoming weather zones (travel area: advanced warning/notification).
- Situation Group C-2: ADS winter-maintenance vehicles detecting weather events (travel area: transition area).
- Situation Group C-3: ADS-equipped vehicles respond to weather events (travel area: transition area).
- Situation Group C-4: ADS-equipped winter-maintenance vehicles responding to weather events (travel area: weather area).
- Situation Group C-5: ADS-equipped vehicles operating within weather event (travel area: weather area).
- Situation Group C-6: ADS-equipped winter-maintenance vehicles close out weather event (travel area: termination area).
- Situation Group C-7: ADS-equipped vehicles react to end of weather event (travel area: termination area).

WZM Use Case

- Situation Group D-1: Notifying ADS-equipped vehicles of upcoming work zones (travel area: advanced warning/notification).
- Situation Group D-2: Communicating with ADS-equipped vehicles setting up work zones (travel area: transition area).
- Situation Group D-3: ADS-equipped vehicles interacting with traffic-control devices (travel area: transition area).
- Situation Group D-4: ADS-equipped vehicles interacting with work-zone workers and flaggers (travel area: transition area).
- Situation Group D-5: ADS-equipped vehicles interacting with people in and around work zones (travel area: activity area).
- Situation Group D-6: ADS-equipped vehicles interacting with work zones on side of road (travel area: activity area).
- Situation Group D-7: ADS-equipped vehicles navigating work zones with lanes blocked (travel area: activity area).

- Situation Group D-8: ADS-equipped vehicles navigating work zones in different configurations (travel area: activity area).
- Situation Group D-9: ADS-equipped work vehicles entering, exiting, or inside work zones (travel area: activity area).
- Situation Group D-10: ADS-equipped work vehicles taking down a work zone (transition area: termination area).

Situations

Examples of various situations are identified under each situation group based on the use case workshop discussions, stakeholder inputs, and adaptations from the *Manual on Uniform Traffic Control Devices* (MUTCD) (FHWA 2009). The situations are not exhaustive, and the situational framework is expected to continue growing as work continues. Each situation is coded by a decimal place. For instance, the example situations under Situation Group 2 in the RWM use case are sequenced A-2.1, A-2.2.

Specifically, the following situation groups were defined to allow stakeholders to prioritize the situations to be investigated as part of the CARMA Platform.

Basic Travel Use Case

Situation Group A-1: Basic Travel Operations for All Roadway Types. Nonspecialized vehicle situations applicable to all roadway types include the following:

- A-1.1: Managing vehicle platooning (e.g., joining, formation, operation, and dissolution).
- A-1.2: Managing vehicle strings (cooperative adaptive cruise control).
- A-1.3: Using cooperative lane changes (when not platooning).
- A-1.4: Supporting hazard detection.
- A-1.5: Identifying vehicle by capabilities (e.g., automation level and cooperation class).
- A-1.6: Screening for overheight/overweight vehicles.
- A-1.7: Parking a vehicle (including onstreet parking).
- A-1.8: Navigating railroad crossings.
- A-1.9: Navigating around school zones.
- A-1.10: Navigating managed-lane facilities (e.g., high-occupancy toll [HOT] lanes).
- A-1.11: Interacting with TCDs (e.g., arrow board devices in the middle lane).

Situation Group A-2: Basic Travel Operations for Highways. Nonspecialized vehicle situations applicable to roadways with intersections that are not at-grade to other roadways, which include interstates and most freeways and expressways, include the following:

- A-2.1: Merging on/diverging off highway (when not platooning).
- A-2.2: Merging on/diverging off highway with platoon.
- A-2.3: Managing active traffic (e.g., speed harmonization).
- A-2.4: Metering ramp with/without traffic signal prompt.

Situation Group A-3: Basic Travel Operations for Arterials. Nonspecialized vehicle situations applicable to nonhighway roadways, which include local streets, collectors, and principal and minor arterials, include the following:

- A-3.1: Navigating signalized intersections (operating in fixed time, traffic responsive, and adaptive).
- A-3.2: Navigating signalized intersections with priority (priority-eligible vehicles).
- A-3.3: Navigating nonsignalized intersections (e.g., all-way stop, median crossing).
- A-3.4: Navigating roundabout (e.g., single lane and multilane).
- A-3.5: Interacting with pedestrians (e.g., pedestrians crossing roadway perpendicularly or crossing side street at intersection with vehicle turning).
- A-3.6: Interacting with bicycles (e.g., bicycles crossing roadway perpendicularly or crossing side street at intersection with turning vehicle).

TIM Use Case

ADS Vehicle Travel Area: Advanced Warning/Notification Area

Situation Group B-1: Notifying ADS-equipped vehicle of incident. ADS-equipped vehicles must be able to receive notifications in real time and for specific incident scenes in their paths. These notifications will be used to plan and, when appropriate, alter travel routes. The following situations are examples of vehicle notifications and warnings prior to arrival at an incident site:

- B-1.1: Road closure with diversion.
- B-1.2: Detour for one travel direction.
- B-1.3: Detour for closed street.
- B-1.4: Overlapping routes with detour.
- B-1.5: Temporary road closure.
- B-1.6: Notification of end of queue.
- B-1.7: Estimated incident duration.
- B-1.8: Incident information for ADS first responders, including incident type, incident location, incident severity, and updates on optimal travel route.

ADS Vehicle Travel Area: Transition Area

Situation Group B-2: ADS first-responder vehicles setting up incident site. First-responder vehicles equipped with ADS must be able to set up the perimeter of an incident site. The following situations are examples of incident-site setups:

- B-2.1: Vehicle setting up first-responder vehicle locations at incident site.
- B-2.2: Vehicle setting up cones to divert traffic around incident site.
- B-2.3: First-responder vehicles broadcasting positions to other ADS-equipped vehicles and the TMS at incident site.

Situation Group B-3: ADS-equipped vehicles interacting with first-responder vehicles approaching incident site. ADS-equipped vehicles must be able to cooperate with

first-responder vehicles approaching an incident site. The following situations are examples of such cooperation:

- B-3.1: Vehicle moves out of the way and clears space for first-responder vehicles driving toward an incident (i.e., traffic interaction with emergency vehicles).
- B-3.2: First-responder vehicles setting up cones to divert traffic around incident site.
- B-3.3: First-responder vehicles broadcasting positions on way to incident site.
- B-3.4: Establishing geofence around incident scene.
- B-3.5: Identifying back-of-queue (queue management).

Situation Group B-4: ADS-equipped vehicles approaching incident site. ADS-equipped vehicles must be able to address a range of situations when approaching an incident site, including the following:

- B-4.1: Secondary incidents between vehicles approaching incident site.
- B-4.2: Incidents involving first-responder vehicles.

Situation Group B-5: ADS-equipped vehicles interacting with traffic-control devices. ADS-equipped vehicles must be able to recognize TCDs and the message/information the device is conveying. For example, an ADS-equipped vehicle should not confuse a cone or barrier as an obstruction and come to a halt, but instead recognize and understand the need to merge into another lane. The following items are examples of TCDs used in work zones:

- B-5.1: Police vehicles with flashing lights warning of an immediate downstream incident site.
- B-5.2: Cones separating an incident site from available roadway lanes.

Situation Group B-6: ADS-equipped vehicles interacting with first-responder personnel warning of incident site. ADS-equipped vehicles must be able to recognize first-responders positioned in advance of an incident site. For example, an ADS-equipped vehicle must recognize humans warning of an incident site, avoid collisions with humans, and convey the detection of humans to other vehicles (e.g., cooperative and collaborative behavior). The following situation is an example of interaction with humans in work zones:

- B-6.1: Hand-signaling by police officers or other authorized personnel.

ADS Vehicle Travel Area: Activity Area

Situation Group B-7: ADS-equipped vehicles interacting with people at or in incident site. ADS-equipped vehicles must be able to recognize people moving at the periphery and crossing open lanes within an incident site. For example, an ADS-equipped vehicle must recognize humans crossing and working or walking alongside a lane within an incident site and come to a stop to avoid collisions, while at the same time conveying the detection of humans to other vehicles (cooperative and collaborative behavior). The following situations are examples of interactions between the ADS-equipped vehicle and humans:

- B-7.1: Person crossing roadway within an incident site.
- B-7.2: Person working or walking along a lane within an incident site.
- B-7.3: First responder stepping out of vehicle.

Situation Group B-8: ADS-equipped vehicles interacting with incident site on side of road. ADS-equipped vehicles must be able to recognize an incident site on the side of the road (i.e., on the shoulder) that does not close travel lanes. The following situations are examples of interactions between the ADS-equipped vehicle and an incident site on the side of the road:

- B-8.1: Incident on shoulder (e.g., a disabled vehicle or traffic stop).
- B-8.2: Shoulder incident with minor encroachment of roadway.
- B-8.3: Incident on onramp or exit ramp.
- B-8.4: First responder stepping out of vehicle.
- B-8.5: First-responder vehicles broadcasting their positions at site.
- B-8.6: Move-Over law.

Situation Group B-9: ADS-equipped vehicles navigating incident site with lanes blocked. ADS-equipped vehicles must be able to recognize lane drops prior to an incident site. Lane drops can include multiple lane drops when drops are staggered, but at least one through lane remains open. This grouping covers incident sites on either side of the roadway and stranded vehicles in the middle lanes. The following situations are examples of ADS-equipped vehicles navigating an incident site with blocked lanes:

- B-9.1: One-lane, two-way traffic taper.
- B-9.2: Lane closure on two-lane road.
- B-9.3: Lane closure at intersection (e.g., right- or left-hand, near- or far-side, multiple-lane, half road, center, or side).
- B-9.4: Half-road closure on the far side of intersection.
- B-9.5: Multiple lane closures at intersection.
- B-9.6: Closure in center of intersection.
- B-9.7: Interior lane closure on multilane street.
- B-9.8: Half-road closure on multilane, high-speed highway.
- B-9.9: Lane closure on divided highway.
- B-9.10: Lane closure with temporary traffic barrier.
- B-9.11: Double-lane closure on freeway.
- B-9.12: Interior-lane closure on freeway.
- B-9.13: Incident in vicinity of grade crossing.
- B-9.14: Lane shift on freeway.
- B-9.15: Incident in vicinity of the exit ramp.
- B-9.16: Incident in vicinity of the entrance ramp.
- B-9.17: Middle lanes on freeway closed and through traffic passes on both sides.
- B-9.18: Middle lanes on arterial closed and through traffic passes on both sides in same or opposite directions.
- B-9.19: Median crossover on freeway.
- B-9.20: Median crossover for entrance ramp.

- B-9.21: Median crossover for exit ramp.
- B-9.22: Temporary reversible lane using movable barriers.

Situation Group B-10: ADS first-responder vehicles entering, exiting, or inside incident site. First-responder vehicles equipped with ADS must be able to enter and exit an incident site regardless of whether the entry or exit points are midblock of the site or at the end of the site. The following situations are examples of ADS-equipped first-responder vehicles entering and exiting an incident site:

- B-10.1: Entering incident site at midpoint.
- B-10.2: Exiting incident site at midpoint.
- B-10.3: Entering incident site by reversing into the back end of incident site.
- B-10.4: Exiting incident site by reversing out of the back end of incident site.
- B-10.5: Detecting and interacting with first responders at incident site.

ADS Vehicle Travel Area: Termination Area

Situation Group B-11: ADS first-responder vehicles clearing incident site. First-responder vehicles equipped with ADS must be able to assist with cleaning an incident site and clearing the roadway for recovery. The following situations are examples of first-responders cleaning and clearing an incident site:

- B-11.1: Vehicle performing key actions, such as towing vehicles and cleaning roadway of spilled materials.
- B-11.2: Vehicle removing cones demarcating incident site.
- B-11.3: Vehicle sending notifications announcing incident clearance.

RWM Use Case

ADS Vehicle Travel Area: Advanced Warning/Notification of Road Weather

Situation Group C-1: Notifying ADS-equipped vehicles of upcoming weather zones. ADS-equipped vehicles must be able to receive notifications of approaching weather hours in advance or on an as-needed basis as conditions warrant. These advanced and as-needed notifications will be used to plan for and respond to weather conditions, and potentially to alter travel routes. The following situations are examples of notifications and warnings in advance of weather areas:

- C-1.1: Detect road weather and pavement conditions.
- C-1.2: Detect extreme weather events (e.g., low to zero visibility, treacherous/impassable roads, abandoned cars).
- C-1.3: Detect road weather events (e.g., major storms, floods, high winds).
- C-1.4: Geofence to indicate areas not plowed during and after the snow event.
- C-1.5: Geofence to show roadway/lanes blocked due to weather.
- C-1.6: Employ weather-responsive traffic signals/ramp metering.

- C-1.7: Employ weather-responsive variable message sign (VMS) messaging (Dudek et al. 2006).
- C-1.8: Employ signal preemption for maintenance vehicles.
- C-1.9: Automated snowplowing.
- C-1.10: Automated snowplowing (specialized; e.g., bridges and work zones).
- C-1.11: Platooning under adverse-weather conditions.
- C-1.12: Road closure due to weather conditions with diversion.
- C-1.13: Road closure due to weather conditions with off-area detour.
- C-1.14: Employee weather-responsive control strategies (e.g., VSL, chain, and/or tire requirements).

ADS Vehicle Travel Area: Transition Area

Situation Group C-2: ADS winter-maintenance vehicles detecting weather events. Winter-maintenance vehicles equipped with ADS must be able to detect and report the beginning of the weather-event area. The following situations are examples of the detection and reporting:

- C-2.1: Vehicle detects weather-event area.
- C-2.2: Vehicle reports on weather-event area.

Situation Group C-3: ADS-equipped vehicles respond to weather events. ADS-equipped vehicles must be able to adjust their travel at the beginning of the weather-event area. The following situations are examples of adjusting travel at the beginning of a weather event:

- C-3.1: Vehicle adjusts speeds and prepares for other adjustments at the beginning of the weather-event area.
- C-3.2: Vehicle informs vehicle operator and pulls over so operator can place chains on vehicle's tires prior to arriving at the weather-event area.

ADS Vehicle Travel Area: Weather Area

Situation Group C-4: ADS winter-maintenance vehicles responding to weather events. Winter-maintenance vehicles equipped with ADS must be able to work and respond to weather events. The following situations are examples of ADS-equipped vehicles working and responding to weather events:

- C-4.1: Vehicle conveys it is working the weather event (e.g., using hazard lights).
- C-4.2: Vehicle dispenses treatment onto roadways according to the current weather-response plan.
- C-4.3: Snowplow operates independently as a unit.
- C-4.4: Snowplows operate collaboratively as coordinated units.

Situation Group C-5: ADS-equipped vehicles operating within weather event. ADS-equipped vehicles, having adjusted their travel at the beginning of the weather-event zone, move through the weather-event area or seek shelter. The following situations are examples of ADS-equipped vehicles driving through or seeking shelter from the weather event:

- C-5.1: Vehicle carefully drives through weather-event area.
- C-5.2: Vehicle seeks shelter, which might include parking the vehicle to wait for the weather event to end.

ADS Vehicle Travel Area: Termination Area

Situation Group C-6: ADS winter-maintenance vehicles close out weather event. Winter-maintenance vehicles equipped with ADS return to normal and/or clean-up operations after a weather event ends. The following situations are examples of ending the response plan and cleanup activities:

- C-6.1: Vehicle ends weather-event response plan.
- C-6.2: Vehicle performs cleanup operations according to the weather-event management plan and need.
- C-6.3: Vehicle returns to home base.

Situation Group C-7: ADS-equipped vehicles react to end of weather event. ADS-equipped vehicles return to normal operations at the end of a weather event. The following situations are examples of such activities:

- C-7.1: Vehicle adjusts speed to normal operations at the end of the weather event.
- C-7.2: Vehicle operator pulls the vehicle over to the side of the road to remove chains on vehicle at the end of the weather event.

WZM Use Case

ADS Vehicle Travel Area: Advanced Warning/Notification of Work-Zone Area

Situation Group D-1: Notifying ADS-equipped vehicles of upcoming work zones. ADS-equipped vehicles must be able to receive notifications before entering a work zone. This advanced notification is used to plan and potentially alter travel routes used by the ADS-equipped vehicle. An ADS-equipped vehicle must also be able to receive notifications of work zones that were set up on an as needed basis (i.e., utility work), which includes temporary or mobile work zones. The following situations are examples of notification warnings in advance of work zones:

- D-1.1: Road closure with diversion.
- D-1.2: Road closure with offsite detour.
- D-1.3: Detour for one travel direction.
- D-1.4: Detour for closed street.
- D-1.5: Overlapping routes with detour.
- D-1.6: Temporary road closure.
- D-1.7: Work zone on shoulder.
- D-1.8: Work zone closure of lanes.
- D-1.9: Work zone with flagger or traffic-control devices.

ADS Vehicle Travel Area: Transition Area

Situation Group D-2: Communicating with ADS-equipped vehicles setting up work zones. ADS-equipped work vehicles must be able to follow instructions to set up the work zone according to the traffic-management plan, which includes temporary or mobile work zones. The following situations are examples of communicating with ADS-equipped vehicles that set up work zones:

- D-2.1: Work vehicle setting up cones or barrels to delineate the work zone.
- D-2.2: Work vehicle setting up barriers to delineate the work zone.

Situation Group D-3: ADS-equipped vehicles interacting with traffic-control devices. ADS-equipped vehicles must be able to recognize traffic-control devices. For example, an ADS-equipped vehicle must not confuse a cone or barrier as an obstruction and therefore come to a halt; instead, the vehicle must recognize and understand the need to merge into another lane. This includes temporary or mobile work zones. The following situations are examples ADS-equipped vehicles interacting with traffic-control devices:

- D-3.1: Stop/Slow automated flagger assistance device (AFAD).
- D-3.2: Red/yellow-lens AFAD.
- D-3.3: Police vehicles with flashing lights warning of immediate downstream work zone.
- D-3.4: Cones or barriers separating work zone from roadway lanes.

Situation Group D-4: ADS Vehicles Interacting with work-zone workers and flaggers. ADS-equipped vehicles must be able to recognize workers positioned in advance of a work zone. For example, an ADS-equipped vehicle must recognize human flaggers and avoid collision with the flaggers. The ADS-equipped vehicle must also be able to convey the detection of humans to other vehicles (cooperative and collaborative behavior). This includes temporary or mobile work zones. The following items are examples of humans in work zones:

- D-4.1: Hand-signaling devices by flaggers.
- D-4.2: Hand-signaling by police officers or other authorized staff.

ADS Vehicle Travel Area: Activity Area

Situation Group D-5: ADS-equipped vehicles interacting with people in and around work zones. ADS-equipped vehicles must be able to recognize people moving at the periphery and crossing open lanes within a work zone. For example, an ADS-equipped vehicle must recognize humans crossing and working or walking alongside a lane within a work zone and come to a stop to avoid collisions while at the same time convey the detection of humans to other vehicles (cooperative and collaborative behavior). This includes temporary and mobile work zones. The following situations are examples of ADS-equipped vehicles recognizing humans in a work zone:

- D-5.1: Person crossing roadway within a work-zone area.
- D-5.2: Person working or walking along a lane within a work-zone area.

Situation Group D-6: ADS-equipped vehicles interacting with roadside work zones. ADS-equipped vehicles must be able to recognize work zones (and their associated traffic-control devices) that are operating on the side of the road (e.g., the shoulder) but do not close any through lanes. This includes temporary or mobile work zones. The following situations are examples of interactions with roadside-based work zones:

- D-6.1: Shoulder work.
- D-6.2: Short-duration work zone on a shoulder.
- D-6.3: Shoulder closure on freeway.
- D-6.4: Shoulder work with minor encroachment of roadway.
- D-6.5: Partial exit-ramp closure.

Situation Group D-7: ADS-equipped vehicles navigating work zones with lanes blocked. ADS-equipped vehicles must be able to recognize lane drops prior to the work zone. Lane drops can include multiple lane drops when drops are staggered, but at least one through lane remains open. This includes temporary or mobile work zones. The following situations are examples of interactions navigating work zones with blocked lanes:

- D-7.1: One-lane, two-way traffic taper.
- D-7.2: Lane closure on two-lane road using flaggers.
- D-7.3: Lane closure on two-lane road using traffic-control signals.
- D-7.4: Lane closure on a right- or left-hand, near- or far-side, multiple-lane, half-road, center, or side intersection.
- D-7.5: Interior lane closure on multilane street.
- D-7.6: Half-road closure on multilane, high-speed highway.
- D-7.7: Stationary lane closure on divided highway.
- D-7.8: Lane closure with temporary traffic barrier.
- D-7.9: Double-lane closure on freeway.
- D-7.10: Interior-lane closure on freeway.
- D-7.11: Work in vicinity of grade crossing.
- D-7.12: Lane shift on freeway.
- D-7.13: Work in vicinity of exit ramp.

Situation Group D-8: ADS-equipped vehicles navigating work zones in different configurations. ADS-equipped vehicles must be able to recognize lane drops prior to a work zone when the middle lanes are closed and at least one through lane on each side stays open (or where ADS-equipped vehicles need to cross over into opposite lanes). This includes temporary or mobile work zones. The following situations are examples of interactions of ADS-equipped vehicles navigating work zones in different configurations:

- D-8.1: Middle lanes on freeway closed and through traffic passes on both sides.
- D-8.2: Middle lanes on arterial closed and through traffic on both sides passes in same or opposite directions.
- D-8.3: Median crossover on freeway.
- D-8.4: Median crossover for entrance ramp.
- D-8.5: Median crossover for exit ramp.

- D-8.6: Work in vicinity of entrance ramp.
- D-8.7: Temporary reversible lane using movable barriers.
- D-8.8: Counterflow and reverse lanes for work zones.

Situation Group D-9: ADS-equipped work vehicles entering, exiting, or inside work zones. ADS-equipped work vehicles must be able to enter and exit a work zone regardless of whether the entry and exit points are in the middle of the work zone or at the end of the work zone. This includes temporary or mobile work zones. The following situations are examples of such interactions in work zones:

- D-9.1: Entering and exiting in the middle of the work zone.
- D-9.2: Entering and exiting the work zone by backing into the back end of the work zone.
- D-9.3: Detecting and interacting with workers in the work zone.

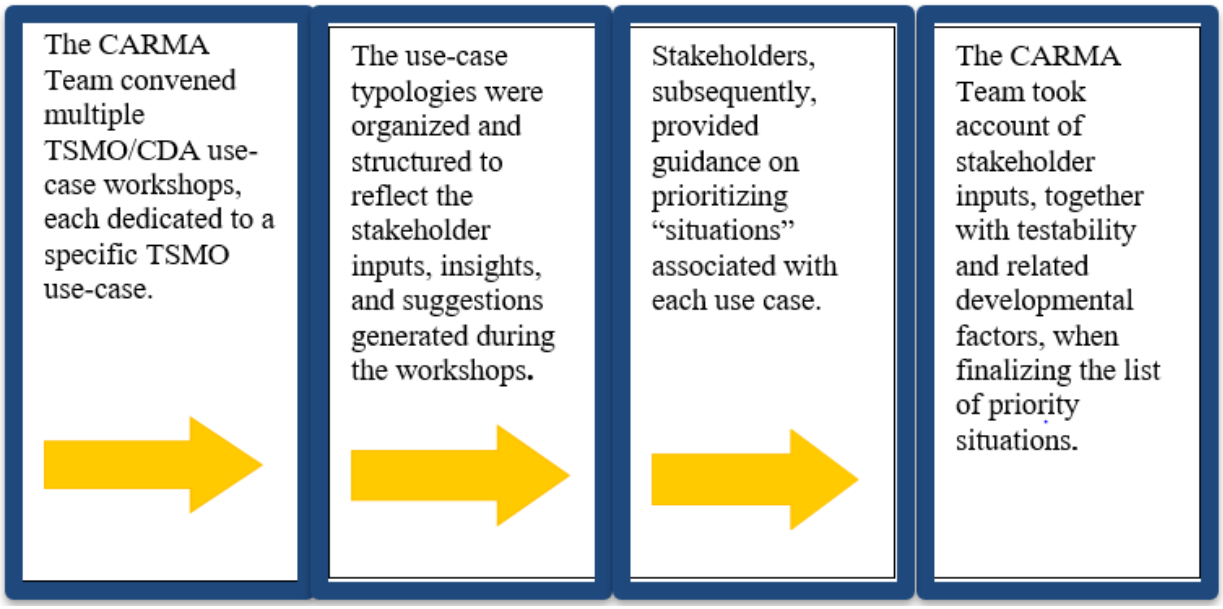
ADS Vehicle Travel Area: Termination Area

Situation Group D-10: ADS-equipped work vehicles dismantling a work zone. ADS-equipped vehicles must be able to follow instructions to dismantle a work zone according to the traffic-management plan. This includes temporary or mobile work zones. The following items are examples of such interactions in work zones:

- D-10.1: Vehicle removing barriers delineating a work zone.
- D-10.2: Vehicle removing a cone.

PRIORITY SITUATIONS BY USE CASE

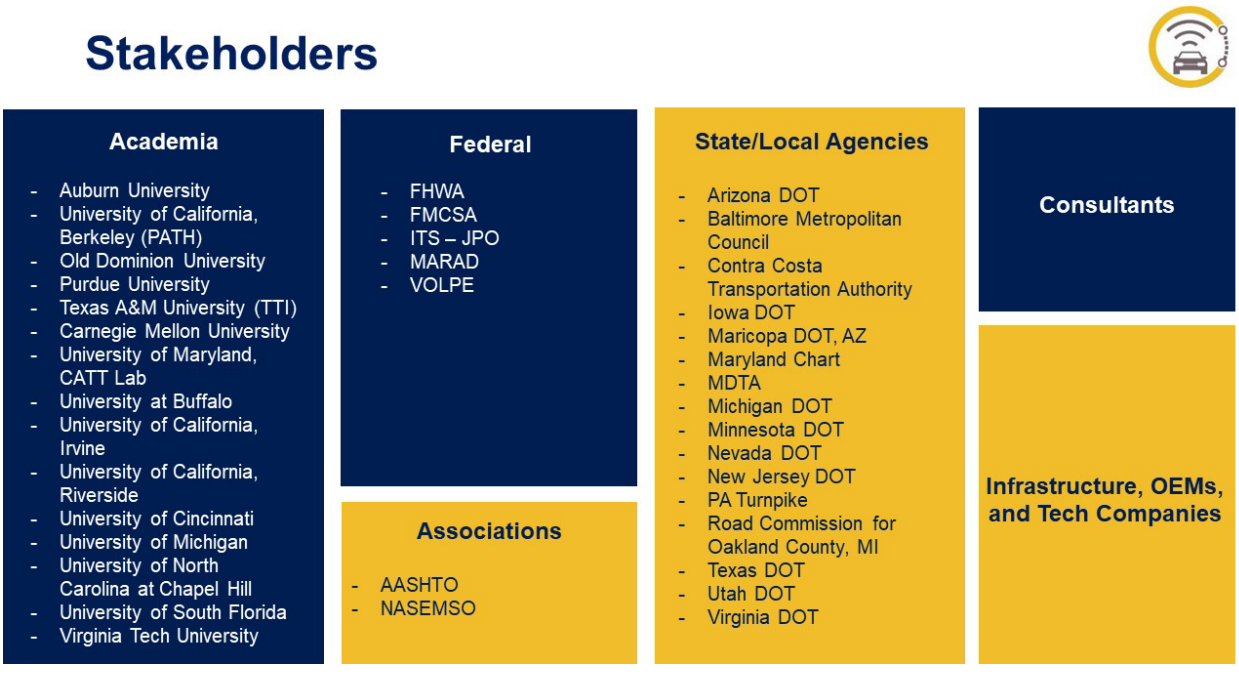
The research team created a prioritization process to choose the most pressing situations for which CARMA team members will develop and field test algorithms to use in ADS-equipped vehicles. The process included the steps shown in figure 3 and involved extensive stakeholder outreach. At the beginning of this project, researchers convened a workshop that included major stakeholders; these stakeholders formed the governing committee. Following the workshop, researchers conducted individual workshops with stakeholders from each of the four use cases. Once the individual workshops were completed, stakeholders participated in a ranking and prioritization exercise for the various priority situations within each use case. The governing committee held a final stakeholder workshop to inform and receive comments on the situations deemed a priority.



Source: FHWA.

Figure 3. Illustration. Prioritization process for choosing situations.

Of the 160 previously identified situations in the preceding sections, stakeholders prioritized 1 or more situations across each of the 4 use cases. Stakeholders across research and academia, State and local agencies, consultants, and other companies were identified, contacted, and invited to participate in the prioritization process. Figure 4 lists some of the stakeholders involved.



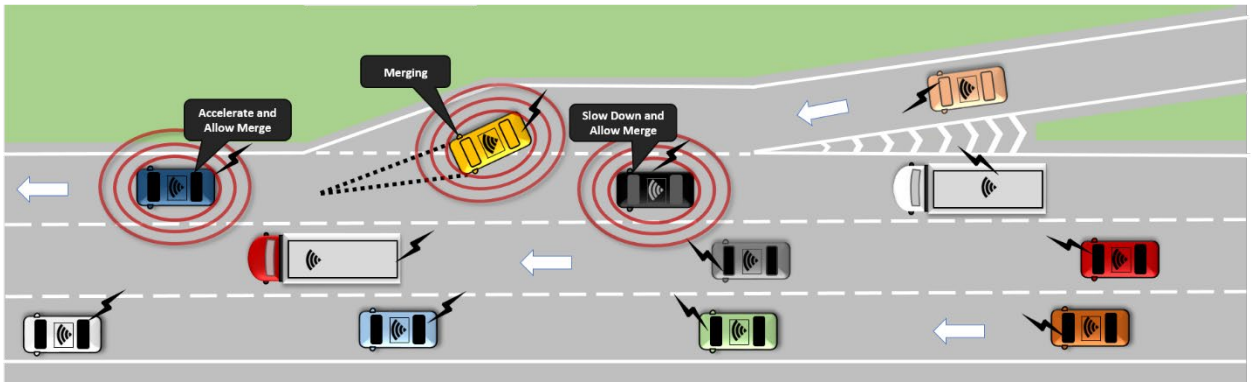
Source: FHWA.

Figure 4. Illustration. Several stakeholder groups and individual stakeholders per group involved in the prioritization process.

Based on stakeholder input, as well as CARMA needs, the highest priority items were determined to be, in descending order, as follows. Figure 5 through figure 8 illustrate the priority situations to be evaluated. All vehicles that have a symbol next to them are equipped with automated driving systems.

Group 1 Priority Situations

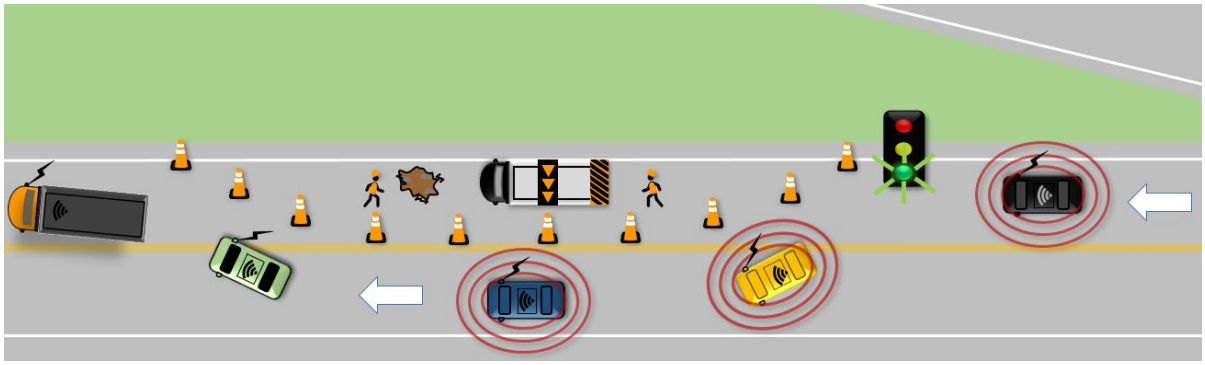
Basic Travel: Merging onto a highway



Source: FHWA.

Figure 5. Illustration. Basic travel: merging onto a highway.

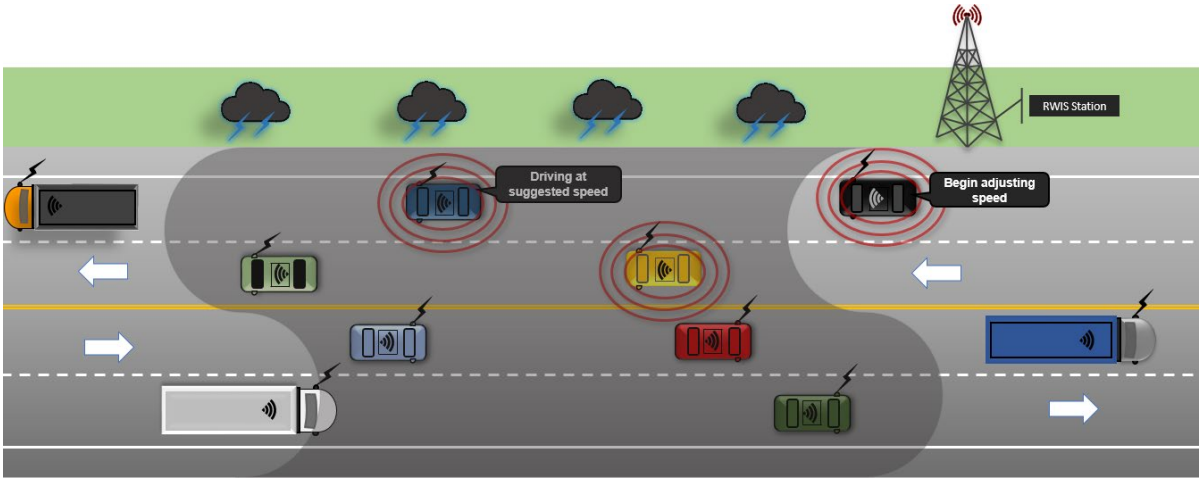
WZM: Vehicles navigating a one-lane, two-way traffic taper in a work zone



Source: FHWA.

Figure 6. Illustration. WZM: Vehicles navigating a one-lane, two-way traffic taper in a work zone.

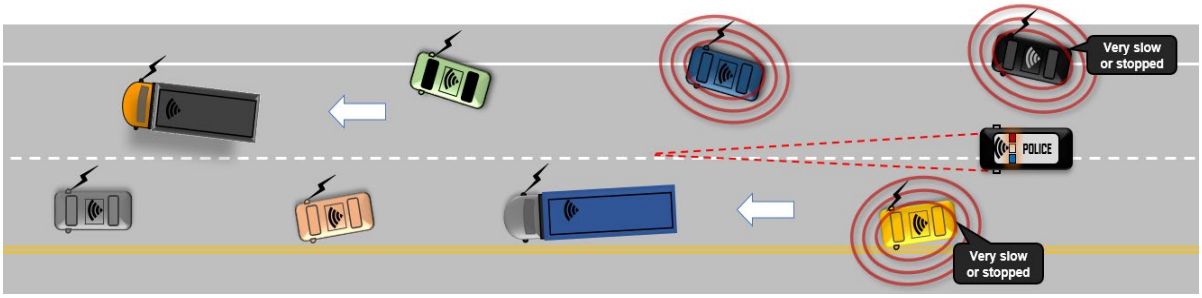
RWM: Vehicle adjusts speed and prepares for other adjustments at beginning of weather-event zone



Source: FHWA.

Figure 7. Illustration. RWM: Vehicle adjusts speed and prepares for other adjustments at beginning of weather-event zone.

TIM: Vehicle moves out of the way and clears space first-responder vehicles driving toward the incident



Source: FHWA.

Figure 8. Illustration. TIM: Vehicle moves out of way and clears space for first-responder vehicles driving toward incident.

Group 2 Priority Situations

CARMA team members will first develop algorithms for the Group 1 priority situations. Team members will develop algorithms for Group 2, detailed in the following list, as a future step. This report focuses on the Group 1 priority situations.

- WZM: Road closure with diversion.
- TIM: Move-Over law. When approaching a stationary emergency vehicle with flashing lights, the approaching traffic moves out of the lane adjacent to the emergency vehicle.
- Basic Travel: Navigate signalized intersection.
- TIM: Lane shift on freeway.

CHAPTER 3. BASIC TRAVEL USE CASE

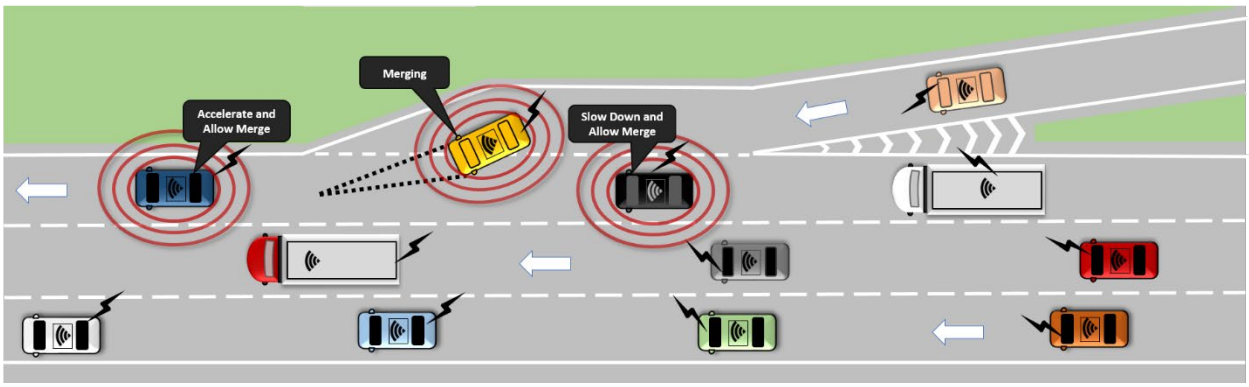
PRIORITY SITUATION 1 TREATMENT: ADS-EQUIPPED VEHICLE MERGING ONTO A HIGHWAY

The subject of this situational analysis of priority situation 1 is an ADS feature with an operational design domain (ODD) that includes ADS-equipped vehicles merging from an onramp onto an acceleration lane on a highway populated by vehicles of different automation levels and cooperation classes.

Priority situation 1 includes ADS vehicle travel areas with various interactions between vehicles equipped and not equipped with ADS. For this situation, the ADS-equipped vehicle travel areas of advanced warning/notification, transition, activity, and termination were used.

Priority situation 1 involves a vehicle driving on the onramp approaching the merge area of the highway. Two vehicles are in the right lane of the highway. All vehicles approach the onramp acceleration lane at the same time, and the vehicle on the ramp attempts to merge onto the highway between the two vehicles traveling in the right lane. This situation considers several vehicle configurations, including different levels of automation and classes of cooperation capabilities among the vehicles.

Figure 9 shows the situational layout of priority situation 1. To investigate this situation, test vehicles with different classes of cooperation capabilities were used. The other vehicles shown in figure 9 are not essential when executing tests in this situation.



Source: FHWA.

Figure 9. Illustration. Basic travel situational layout.

Operational Needs

Priority situation 1 is intended to address specific operational user needs defined in table 2 through table 5.

Table 2. Operational needs of merging onto a highway.

Operational Need Identifier	Operational Needs
BT-N1.01	Improve safety and efficiency of highway merge maneuvers.
BT-N1.02	Maintain situational awareness during merging operations.
BT-N1.03	Gather, integrate, process, and disseminate data.

Table 3. Operational needs for ADS-equipped vehicles merging onto a highway.

Operational Need Identifier	Operational Needs for ADS-Equipped Vehicles
BT-N1.04	Need location and speed information from vehicles near the ADS-equipped vehicle.
BT-N1.05	Need merging vehicle speeds, locations, and braking information from neighboring vehicles.
BT-N1.06	Need main line vehicle speeds, locations, and braking information from neighboring vehicles.
BT-N1.07	Need to detect vehicles incapable of cooperating with other vehicles.

Table 4. Operational needs for non-ADS-equipped vehicles (human driver) merging onto a highway.

Operational Need Identifier	Operational Needs for Non-ADS-Equipped Vehicles (Human Driver)
BT-N1.08	Need advance information regarding approaching ramps.
BT-N1.09	Need visual alerts from vehicles in the vicinity showing intent to merge onto the highway.
BT-N1.10	Need visual alerts from vehicles in the vicinity showing intent to allow vehicle merge from onramp onto the highway.

Table 5. Operational needs for traffic management service.

Operational Need Identifier	Operational Needs for Traffic Management Service
BT-N1.11	Need to gather and process data from intelligent transportation systems (ITS) devices and ADS-equipped vehicles to monitor current traffic conditions.

Stakeholders and Entities

Researchers can execute the operational situation using several vehicles. CARMA's focus is on Automation Level 3 or higher and Cooperation Class B capabilities or higher; although under real-world conditions, other vehicles will also be encountered that will be equipped with lower automation levels and cooperation classes. The following entities, and their associated minimum vehicle configurations, should be considered when executing this operational situation with CARMA:

- Vehicle onramp: ADS-equipped vehicle with Automation Level 3 and Cooperation Class B.
- Vehicle 1 (rear) on mainline lane: ADS-equipped vehicle with Automation Level 3 and Cooperation Class B.
- Vehicle 2 (front) on mainline lane: ADS-equipped vehicle with Automation Level 3 and Cooperation Class B.

Vehicle 1 is the second vehicle on the mainline lanes, and vehicle 2 is the leading vehicle.

Another stakeholder is the TMS operator (or software package) that will monitor the positions of each vehicle for recording and storage purposes. This situation does not include any field device equipment that needs to be managed; therefore, the TMS operator is passive in this situation. If an RSU is used for the communications, then the TMS will need to monitor the communications associated with the RSU.

User-Oriented Operational Description

Concept Diagram

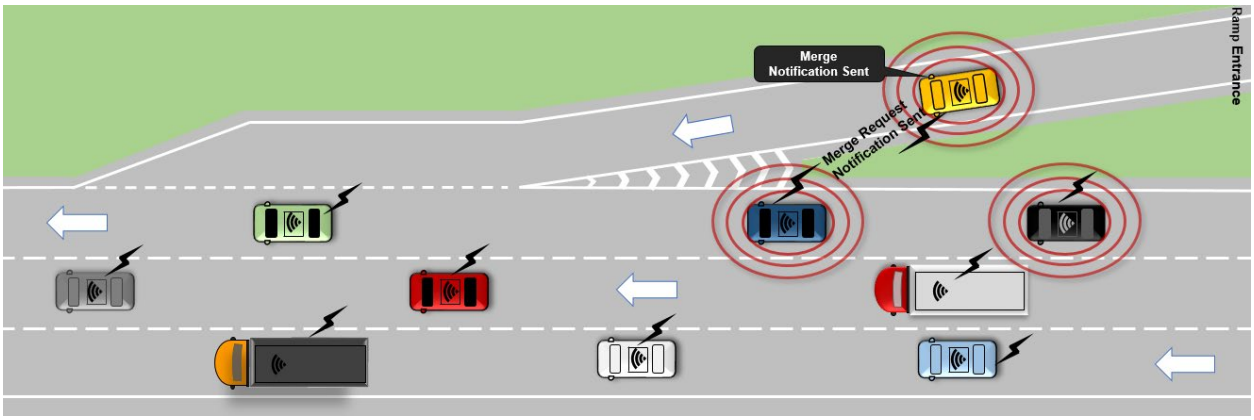
This priority situation 1 includes four ADS-equipped vehicle travel areas—advanced warning/notification, transition, activity, and termination—that are explained in detail and are suitable for this situation. The priority situation concepts include an overview diagram for each travel area for ADS vehicles and a description that shows how vehicles react and respond within each travel area of the "Merge onto Highway" situation.

For the following descriptions of ADS vehicle travel areas used within CARMA, researchers assumed that the involved vehicles support at least Cooperation Class B capabilities.

Advanced Warning/Notification Vehicle Travel Area

Within the advanced warning/notification vehicle travel area, the ADS-equipped vehicle on the ramp broadcasts a notification that it is on the onramp, but not yet on the onramp acceleration lane segment. The information in the notification includes location, speed, and heading.

Each ADS-equipped vehicle on the mainline lanes determines, based on its own location, its speed and heading, and whether it anticipates being impacted by the vehicle on the onramp. For example, in figure 10, the vehicles shown without the circles are assumed not to be affected by the vehicle on the on ramp, while vehicle 1 in the front right-most mainline lane and vehicle 2 in the rear right-most mainline lane expect to be affected.



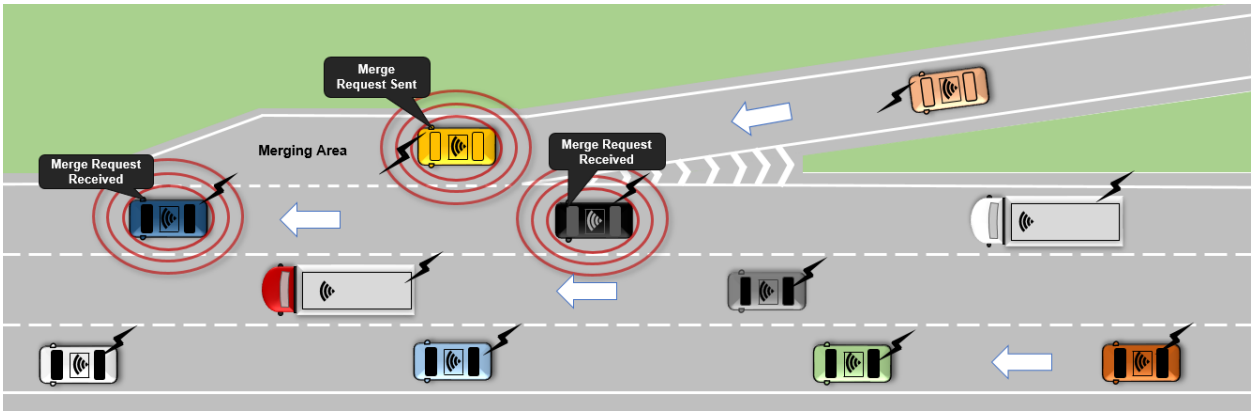
Source: FHWA.

Figure 10. Illustration. Basic travel—ADS-equipped vehicles receiving a notification.

Vehicle Travel Transition Area

Within the transition area, the ADS-equipped vehicle on the ramp broadcasts a notification that it is in the onramp's acceleration lane, as shown in figure 11. This information includes location, speed, and heading, as well as the turn signal, which was turned on by either the vehicle or driver.

Each ADS-equipped vehicle on the mainline lanes receiving a notification determines, based on its own location, its speed and heading, and whether it needs to maintain its current speed, location, and intended path, or whether it should speed up or slow down to accommodate the merging vehicle on the onramp. Vehicles capable of Cooperation Class C exchange data to negotiate how the merging maneuver will be executed. Data exchanges might include interactions between the merging ramp vehicle 1 and the rear mainline lane vehicle 2, during which the vehicle on the ramp speeds up slightly and the vehicle in the rear mainline lane slows down slightly. This is an example of a merge situation at an onramp. Other situations, such as merging in front of mainline vehicles by speeding up or merging behind two mainline vehicles by slowing down, are also possible.



Source: FHWA.

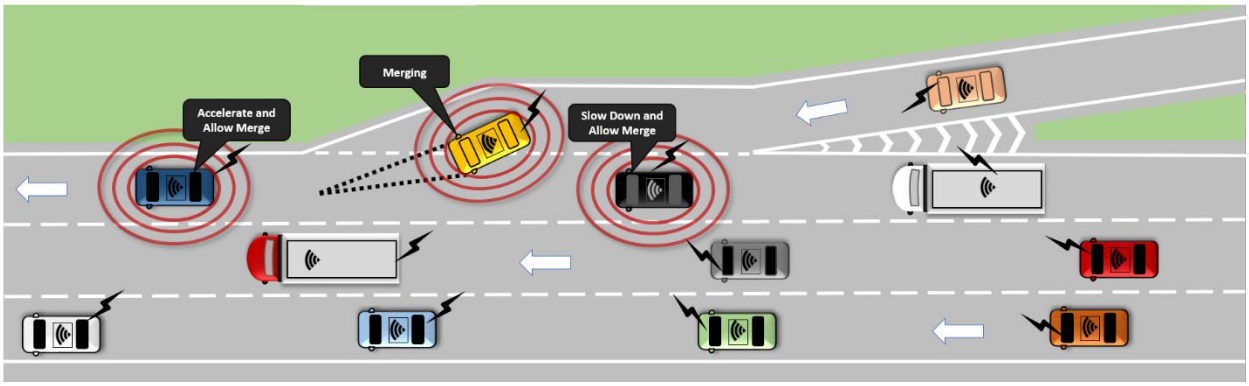
Figure 11. Illustration. Basic travel—vehicle transition area.

Vehicle Travel Activity Area

Within the activity area, the ADS-equipped vehicle on the ramp broadcasts a notification that it is about to move from the onramp's acceleration lane to the mainline lane, shown in figure 12. This information includes location, speed, heading, and brake status (for the rear mainline-lane vehicle), as well as path prediction.

Each ADS-equipped vehicle on the mainline lanes receiving notifications determines, based on its own location, its speed and heading, and whether it needs to maintain its current speed, location, and intended path, or whether it should speed up or slow down slightly to accommodate the merging vehicle on the onramp. The predicted path information from the vehicle on the ramp is used in these determinations. Vehicles capable of Cooperation Class C exchange data to negotiate how the merging maneuver will be executed. This might include data exchanges between vehicle 1 on the ramp and vehicle 2 in the mainline lane. Vehicle 1 on the ramp might

speed up slightly and vehicle 2 on the mainline-lane might slow down slightly to accommodate the merge.



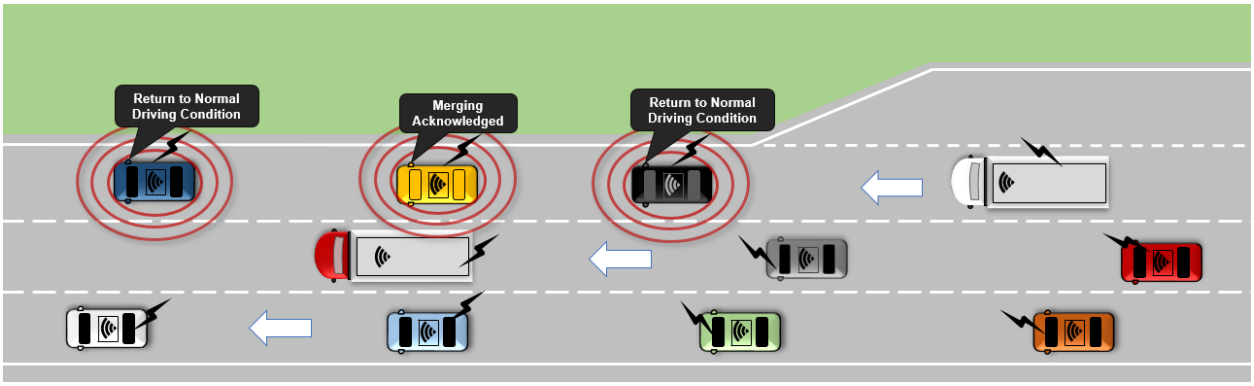
Source: FHWA.

Figure 12. Illustration. Basic travel—vehicle activity area.

Vehicle Travel Termination Area

Within the termination area, the ADS-equipped vehicle that entered the mainline lanes from the ramp finalizes its operational maneuver and broadcasts the completion of its merging activities, as shown in figure 13.

Upon receipt of this information, the ADS-equipped vehicles in the mainline lane return to normal driving operation. This may require vehicle 2 in the rear to speed up to reduce the headway between itself and the merged vehicle 1.



Source: FHWA.

Figure 13. Illustration. Basic travel—termination area.

Trigger to Invoke Situation for Merging onto a Highway

This merging onto the highway situation is triggered by the vehicle on the ramp indicating that it intends to merge onto the highway. The following indicators are designated as triggers to invoke responses of mainline vehicles:

- Broadcast by vehicle equipped with ADS on the ramp.
- Acceleration of any vehicle on the ramp lane next to the mainline lanes.
- Activation of the left-turn signal on the vehicle on the ramp intending to merge onto the highway (this is not a CARMA program consideration).
- Execution of the merging maneuver by the vehicle in the ramp acceleration lane.

All maneuvers by vehicles in the mainline lanes next to the vehicle desiring to merge are considered reactions to the merging vehicle. These maneuvers include speeding up or slowing down as well as safely merging into the mainline lanes to the left.

Requirements for Merging onto a Highway

The requirements for merging onto a highway and fulfilling the stated user-operational needs are defined in table 6.

Table 6. Requirements for merging onto a highway.

Functional Requirement Identifier	Functional Requirement	Applicable to CARMA
BT-R1.01	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall provide for the capability to avoid crashes with other vehicles (vehicles with or without Cooperation Class capabilities) prior to, during, and after completion of the merging maneuver. Communications shall be possible approximately every ⅒ s.	Yes, Cooperation Class B and higher
BT-R1.02	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to broadcast its location, speed, heading, and brake status approximately every ⅒ s.	Yes, Cooperation Class B and higher
BT-R1.03	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use locations, speeds, and headings from other ADS-equipped vehicles with at least Cooperation Class A within its short-range communications approximately every ⅒ s.	Yes, Cooperation Class B and higher
BT-R1.04	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use braking status from other ADS-equipped vehicles with at least Cooperation Class A within its short-range communications approximately every ⅒ s.	Yes, Cooperation Class B and higher
BT-R1.05	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use locations, speeds, and headings from other ADS-equipped vehicles with at least Cooperation Class A via long-range communications within a configurable geofenced area approximately every ⅒ s.	Optional, Cooperation Class B and higher
BT-R1.06	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use braking status from other ADS-equipped vehicles with at least Cooperation Class A capabilities via long-range communications within a configurable geofenced area approximately every ⅒ s.	Optional, Cooperation Class B and higher
BT-R1.07	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to broadcast its driving path for the last 1 min approximately every 1 s.	No
BT-R1.08	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to broadcast its intended future driving path for at least the next 15 s at intervals of approximately every 3 s.	Yes

Functional Requirement Identifier	Functional Requirement	Applicable to CARMA
BT-R1.09	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to interpret received intentions to merge onto a highway and process these intentions in conjunction with the received locations, speeds, headings, and brake status from other ADS-equipped vehicles with Cooperation Class A capabilities or higher.	Yes
BT-R1.10	An ADS-equipped vehicle with Cooperation Class C capabilities shall be able to send and receive, decode, process, analyze, and use detailed intention data, including ACKs and NAKs when cooperating with other ADS-equipped vehicles with Cooperation Class C during the merging process. A NAK is defined as a signal that rejects a previously received message or indicates an error.	Yes
BT-R1.11	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall, upon receipt of merge-intention indications, process this information and either speed up (if slightly ahead of a merging vehicle) or slow down (if slightly behind a merging vehicle) to make space for a vehicle to merge onto a highway.	Yes
BT-R1.12	An ADS-equipped vehicle with no cooperative automation capabilities driving on the highway shall be able to determine that it is approaching an onramp.	Yes
BT-R1.13	An ADS-equipped vehicle with no cooperative automation capabilities driving on an arterial, and desiring to drive onto an intersecting highway, shall be able to determine its location and recognize that it is entering and driving on a ramp.	No
BT-R1.14	An ADS-equipped vehicle with no cooperative automation capabilities shall be able to use onboard sensors to detect the location, speed, and heading at suitable sensing intervals of non-ADS-equipped vehicles without Cooperation Class capabilities within its vicinity.	Yes
BT-R1.15	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to detect the turn-signal status of a non-ADS equipped vehicle without Cooperation Class capabilities (assuming there is a clear line of sight).	No
BT-R1.16	An ADS-equipped vehicle shall have a way to visually display to the driver the location of other vehicles about which it has information.	Optional
BT-R1.17	A TMS shall be able to receive aggregated data (e.g., locations, speeds, headings, and brake status) from each ADS-equipped vehicle with at least Cooperation Class A in a specified area. Communications shall be possible approximately every 1 s via short- or long-range communications infrastructure to the TMS.	Yes

ACK = acknowledgment; NAK = negative acknowledgment.

Performance Metrics

Key performance metrics for monitoring and evaluating operations during execution of this situation, some of which were adapted from *A Framework for Automated Driving System Testable Cases and Scenarios*, should include the following:

- Separation distances—longitudinal distances between the vehicles in the test. Separation distances are used to determine safe distances and the frequency of infringement of those distances (Thorn et al. 2018).

- Disengagements—occurrence frequency when safety drivers deactivate the ADS feature being tested and take manual control of the vehicles (Thorn et al. 2018).
- Travel speeds driven—speeds driven by each of the vehicles during the tests will be used to create an accurate picture (playback) for evaluating driving within the vehicle travel areas.
- Speed change—changes in speeds of the vehicles above or below a specified threshold in response to interactions between ADS-equipped vehicles (i.e., reduction in speeds by the vehicle on the ramp moving onto the highway and reductions/maintenance of the mainline vehicles' speeds).
- Data exchanges during negotiation (Cooperation Class C)—capture all data exchanges between two Cooperation Class C ADS-equipped vehicles to determine whether the maneuver negotiations occurred as designed. The data exchanges include the following data types:
  - Total duration of negotiation process.
  - Frequency of negotiation success/failure (negative acknowledgments [NAKs] from neighboring vehicles).
  - Number of attempts before a plan is accepted by all affected neighbors.
  - Message latency. The time difference between vehicle 1 sending the message and vehicle 2 reading the message. The latency time includes the time to compose the message, sending it from vehicle 1's guidance computer to vehicle 1's Onboard Unit (OBU), the queuing time on vehicle 1's OBU, the radio transmission from vehicle 1 to vehicle 2, the message constitution and queueing on vehicle 2's OBU, sending the message from vehicle 2's OBU to vehicle 2's guidance computer, and the time for vehicle 2's decomposition and reading time.

Requirements Traceability Matrix for Operational Needs and Functional Requirements

Table 7 traces the relationship between operational needs and functional requirements.

Table 7. Requirements traceability matrix for merging onto a highway.

Operational Need Identifier	Operational Need	Functional Requirement Identifier	Functional Requirement
BT-N1.01	Improve safety and efficiency of highway merge maneuvers.	BT-R1.01	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall provide for the capability to avoid crashes with other vehicles (vehicles with or without Cooperation Class capabilities) prior to, during, and after completion of the merging maneuver. Communications shall be possible approximately every ⅒ s.
BT-N1.02	Maintain situational awareness during merging operations.	BT-R1.02	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to broadcast its location, speed, heading, and brake status at approximately every ⅒ s.
BT-N1.02	Maintain situational awareness during merging operations.	BT-R1.03	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use locations, speeds, and headings from other ADS-equipped vehicles with at least Cooperation Class A within its short-range communications range approximately every ⅒ s.
BT-N1.02	Maintain situational awareness during merging operations.	BT-R1.04	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use braking status from other ADS-equipped vehicles with at least Cooperation Class A capabilities within its short-range communications range approximately every ⅒ s.
BT-N1.02	Maintain situational awareness during merging operations.	BT-R1.05	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use locations, speeds, and headings from other ADS-equipped vehicles with at least Cooperation Class A capabilities via long-range communications within a configurable geofenced area approximately every ⅒ s.
BT-N1.02	Maintain situational awareness during merging operations.	BT-R1.06	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use braking status from other ADS-equipped vehicles with at least Cooperation Class A capabilities via long-range communications within a configurable geofenced area approximately every ⅒ s.
BT-N1.02	Maintain situational awareness during merging operations.	BT-R1.07	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to broadcast its driving path for the last 1 min approximately every 1 s.
BT-N1.02	Maintain situational awareness during merging operations.	BT-R1.12	An ADS-equipped vehicle with no cooperative automation capabilities driving on the highway shall be able to determine that it is approaching an onramp.
BT-N1.02	Maintain situational awareness during merging operations.	BT-R1.13	An ADS-equipped vehicle with no cooperative automation capabilities driving on an arterial, and desiring to drive onto an intersecting highway, shall be able to determine its location and recognize that it is entering and driving on a ramp.

Operational Need Identifier	Operational Need	Functional Requirement Identifier	Functional Requirement
BT-N1.02	Maintain situational awareness during merging operations.	BT-R1.14	An ADS-equipped vehicle with no cooperative automation capabilities shall be able to use onboard sensors to detect non-ADS-equipped vehicles without Cooperation Class capabilities within its vicinity, including the vehicle's location, speed, and heading at suitable sensing intervals.
BT-N1.02	Maintain situational awareness during merging operations.	BT-R1.15	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to detect the turn-signal status of a non-ADS-equipped vehicle without Cooperation Class capabilities (assuming there is a clear line of sight).
BT-N1.03	Ability to gather, integrate, process, and disseminate data.	BT-R1.02	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to broadcast its location, speed, heading, and brake status approximately every ⅒ s.
BT-N1.03	Ability to gather, integrate, process, and disseminate data.	BT-R1.03	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use locations, speeds, and headings from other ADS-equipped vehicles with at least Cooperation Class A capabilities within its short-range communications range approximately every ⅒ s.
BT-N1.03	Ability to gather, integrate, process, and disseminate data.	BT-R1.04	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use braking status from other ADS-equipped vehicles with at least Cooperation Class A capabilities within its short-range communications range approximately every ⅒ s.
BT-N1.03	Ability to gather, integrate, process, and disseminate data.	BT-R1.05	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use locations, speeds, and headings from other ADS-equipped vehicles with at least Cooperation Class A capabilities via long-range communications within a configurable geofenced area approximately every ⅒ s.
BT-N1.03	Ability to gather, integrate, process, and disseminate data.	BT-R1.06	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use braking status from other ADS-equipped vehicles with at least Cooperation Class A capabilities via long-range communications within a configurable geofenced area approximately every ⅒ s.
BT-N1.03	Ability to gather, integrate, process, and disseminate data.	BT-R1.07	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to broadcast its driving path for the last 1 min approximately every 1 s.
BT-N1.03	Ability to gather, integrate, process, and disseminate data.	BT-R1.08	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to broadcast its intended future driving path for at least the next 15 s at intervals of approximately every 3 s.

Operational Need Identifier	Operational Need	Functional Requirement Identifier	Functional Requirement
BT-N1.03	Ability to gather, integrate, process, and disseminate data.	BT-R1.09	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to interpret received intentions to merge onto a highway and process these intentions in conjunction with the received locations, speeds, headings, and brake status from other ADS-equipped vehicles with Cooperation Class A capabilities or higher.
BT-N1.03	Ability to gather, integrate, process, and disseminate data.	BT-R1.10	An ADS-equipped vehicle with Cooperation Class C capabilities shall be able to send, receive, decode, process, analyze, and use detailed intention data including ACKs and NAKs when cooperating with other ADS-equipped vehicles with Cooperation Class C capabilities during the merging process.
BT-N1.04	Need for location and speed information from vehicles near the ADS-equipped vehicle.	BT-R1.03	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use locations, speeds, and headings from other ADS-equipped vehicles with at least Cooperation Class A capabilities within its short-range communications approximately every ⅒ s.
BT-N1.04	Location and speed information from vehicles near the ADS-equipped vehicle.	BT-R1.04	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use braking status from other ADS-equipped vehicles with at least Cooperation Class A capabilities within its short-range communications range approximately every ⅒ s.
BT-N1.04	Location and speed information from vehicles near the ADS-equipped vehicle.	BT-R1.05	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use locations, speeds, and headings from other ADS-equipped vehicles with at least Cooperation Class A capabilities via long-range communications within a configurable geofenced area approximately every ⅒ s.
BT-N1.04	Location and speed information from vehicles near the ADS-equipped vehicle.	BT-R1.06	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use braking status from other ADS-equipped vehicles with at least Cooperation Class A capabilities via long-range communications within a configurable geofenced area approximately every ⅒ s.
BT-N1.05	Merging vehicle speeds, locations, and braking information from neighboring vehicles.	BT-R1.03	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use locations, speeds, and headings from other ADS-equipped vehicles with at least Cooperation Class A capabilities within its short-range communications range approximately every ⅒ s.

Operational Need Identifier	Operational Need	Functional Requirement Identifier	Functional Requirement
BT-N1.05	Merging vehicle speeds, locations, and braking information from neighboring vehicles.	BT-R1.04	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use braking status from other ADS-equipped vehicles with at least Cooperation Class A capabilities within its short-range communications range approximately every ⅒ s.
BT-N1.05	Merging vehicle speeds, locations, and braking information from neighboring vehicles.	BT-R1.05	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use locations, speeds, and headings from other ADS-equipped vehicles with at least Cooperation Class A capabilities via long-range communications within a configurable geofenced area approximately every ⅒ s.
BT-N1.05	Merging vehicle speeds, locations, and braking information from neighboring vehicles.	BT-R1.06	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use braking status from other ADS-equipped vehicles with at least Cooperation Class A capabilities via long-range communications within a configurable geofenced area approximately every ⅒ s.
BT-N1.05	Merging vehicle speeds, locations, and braking information from neighboring vehicles.	BT-R1.09	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to interpret received intentions to merge onto a highway and process these intentions in conjunction with the received locations, speeds, headings, and brake status from other ADS-equipped vehicles with Cooperation Class A capabilities or higher.
BT-N1.05	Merging vehicle speeds, locations and braking information from neighboring vehicles.	BT-R1.10	An ADS-equipped vehicle with Cooperation Class C capabilities shall be able to send and receive, decode, process, analyze, and use detailed intention data including ACKs and NAKs when cooperating with other ADS-equipped vehicles with Cooperation Class C capabilities during the merging process.
BT-N1.05	Merging vehicle speeds, locations, and braking information from neighboring vehicles.	BT-R1.14	An ADS-equipped vehicle with no cooperative automation capabilities shall be able to use onboard sensors to detect the location, speed, and heading at suitable sensing intervals of non-ADS-equipped vehicles without Cooperation Class capabilities within its vicinity.
BT-N1.05	Merging vehicle speeds, locations, and braking information from neighboring vehicles.	BT-R1.15	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to detect the turn-signal status of a non-ADS-equipped vehicle without Cooperation Class capabilities (assuming there is a clear line of sight).
BT-N1.06	Main line vehicle speeds, locations, and braking information from neighboring vehicles.	BT-R1.03	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use locations, speeds, and headings from other ADS-equipped vehicles with at least Cooperation Class A capabilities within the vehicle's short-range communications range approximately every ⅒ s.

Operational Need Identifier	Operational Need	Functional Requirement Identifier	Functional Requirement
BT-N1.06	Main line vehicle speeds, locations, and braking information from neighboring vehicles.	BT-R1.04	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use braking status from other ADS-equipped vehicles with at least Cooperation Class A capabilities within its short-range communications approximately every ⅒ s.
BT-N1.06	Main line vehicle speeds, locations, and braking information from neighboring vehicles.	BT-R1.05	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use locations, speeds, and headings from other ADS-equipped vehicles with at least Cooperation Class A capabilities via long-range communications within a configurable geofenced area approximately every ⅒ s.
BT-N1.06	Main line vehicle speeds, locations, and braking information from neighboring vehicles.	BT-R1.06	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use braking status from other ADS-equipped vehicles with at least Cooperation Class A capabilities via long-range communications within a configurable geofenced area approximately every ⅒ s.
BT-N1.06	Main line vehicle speeds, locations, and braking information from neighboring vehicles.	BT-R1.09	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to interpret received intentions to merge onto a highway and process these intentions in conjunction with the received locations, speeds, headings, and brake status from other ADS-equipped vehicles with Cooperation Class A capabilities or higher.
BT-N1.06	Main line vehicle speeds, locations, and braking information from neighboring vehicles.	BT-R1.10	An ADS-equipped vehicle with Cooperation Class C capabilities shall be able to send, receive, decode, process, analyze, and use detailed intention data, including ACKs and NAKs when cooperating with other ADS-equipped vehicles with Cooperation Class C capabilities during the merging process.
BT-N1.06	Main line vehicle speeds, locations, and braking information from neighboring vehicles.	BT-R1.11	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall, upon receipt of merge-intention indications, process the merge information and either speed up if slightly ahead of a merging vehicle or slow down if slightly behind a merging vehicle to make space for a vehicle to merge onto a highway.
BT-N1.07	Detect vehicles incapable of cooperating with other vehicles.	BT-R1.14	An ADS-equipped vehicle with no cooperative automation capabilities shall be able to use onboard sensors to detect the location, speed, and heading at suitable sensing intervals of non-ADS-equipped vehicles without Cooperation Class capabilities within its vicinity.
BT-N1.07	Detect vehicles incapable of cooperating with other vehicles.	BT-R1.15	An ADS-equipped vehicle with no cooperative automation capabilities shall be able to detect the turn-signal status of a non-ADS-equipped vehicle without Cooperation Class capabilities (assuming there is a clear line of sight).

Operational Need Identifier	Operational Need	Functional Requirement Identifier	Functional Requirement
BT-N1.08	Advance information regarding approaching ramps.	BT-R1.08	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to broadcast its intended future driving path for at least the next 15 s at intervals of approximately every 3 s.
BT-N1.08	Advance information regarding approaching ramps.	BT-R1.12	An ADS-equipped vehicle with no cooperative automation capabilities driving on the highway shall be able to determine that it is approaching an onramp.
BT-N1.08	Advance information regarding approaching ramps.	BT-R1.13	An ADS-equipped vehicle with no cooperative automation capabilities driving on an arterial and desiring to drive onto an intersecting highway shall be able to determine its location and recognize that it is entering and driving on a ramp.
BT-N1.09	Visual alerts from vehicles in the vicinity showing intent to merge onto the highway.	BT-R1.15	An ADS-equipped vehicle with no cooperative automation capabilities shall be able to detect the turn-signal status of a non-ADS-equipped vehicle without Cooperation Class capabilities (assuming there is a clear line of sight).
BT-N1.09	Visual alerts from vehicles in the vicinity showing intent to merge onto the highway	BT-R1.16	An ADS-equipped vehicle shall have a way to visually display to the driver the location of other vehicles about which it has information.
BT-N1.10	Visual alerts from vehicles in the vicinity showing intent to allow vehicle merge from onramp onto the highway.	BT-R1.09	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to interpret received intentions to merge onto a highway and process these intentions in conjunction with the received locations, speeds, headings, and brake status from other ADS-equipped vehicles with Cooperation Class A capabilities or higher.
BT-N1.10	Visual alerts from vehicles in the vicinity showing intent to allow vehicle merge from onramp onto the highway.	BT-R1.10	An ADS-equipped vehicle with Cooperation Class C capabilities shall be able to send, receive, decode, process, analyze, and use detailed intention data including ACKs and NAKs when cooperating with other ADS-equipped vehicles with Cooperation Class C capabilities during the merging process.
BT-N1.10	Visual alerts from vehicles in the vicinity showing intent to allow vehicle merge from onramp onto the highway.	BT-R1.16	An ADS-equipped vehicle shall have a way to visually display to the driver the location of other vehicles about which it has information.
BT-N1.11	Gather and process data from ITS devices and ADS-equipped vehicles to monitor current traffic conditions.	BT-R1.17	A TMS shall be able to receive aggregated data (e.g., locations, speeds, headings, and brake status) from each ADS-equipped vehicle with at least Cooperation Class A capabilities in a specified area. Communications shall be possible approximately every 1 s via short- or long-range communications infrastructure to the TMS.

ACK = acknowledgment.

CHAPTER 4. USE CASE: TIM

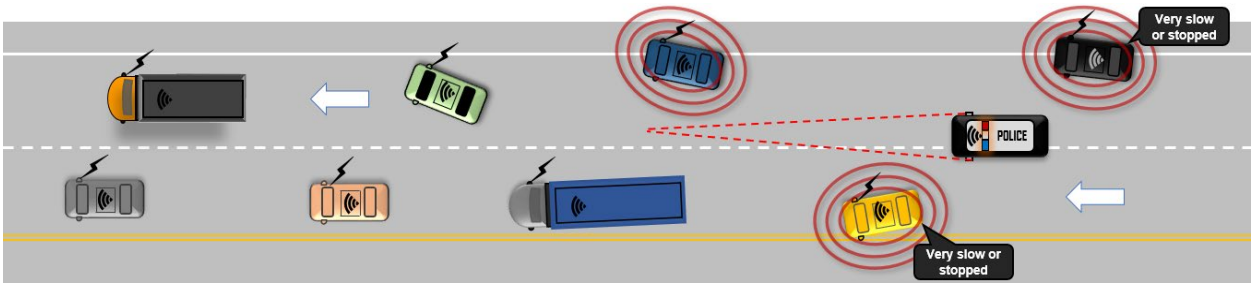
PRIORITY SITUATION 2 TREATMENT: VEHICLE MOVES OUT OF THE WAY OF AN ADS-EQUIPPED EMERGENCY/FIRST-RESPONDER VEHICLE

The subject of this situational analysis is an ADS feature with a specified ODD that includes operation of ADS-equipped vehicles moving out of the way of an ADS-equipped emergency or first-responder vehicle as quickly and safely as possible. In this situation, the emergency vehicle will be responding to a traffic incident, and the roadway is populated by vehicles of different Automation Levels and Cooperation Classes.

The ADS-equipped first-responder vehicle travels through the ADS vehicle travel areas of advanced warning/notification, transition, activity, and termination. These travel areas are defined in chapter 2.

Priority situation 2 involves several vehicles positioned relatively close on both lanes of a two-lane roadway (for testing this situation, vehicles moving in only one direction of travel will be sufficient). A first-responder vehicle responding to an incident approaches the vehicles from behind. The incident site and location are irrelevant for this situation. Depending on the location and availability of shoulder space, the first-responder vehicle can approach the other vehicles from the left or right side or the middle along the direction of travel. For situation 2, the emergency vehicle approaches through the middle of the roadway and other vehicles move to the left shoulder if traveling in the left lane and to the right shoulder if traveling in the right lane. This situation considers several vehicle configurations, including different levels of automation and classes of cooperation capabilities among the vehicles.

The situational layout is depicted in figure 14. Circles surround vehicles with different Cooperation Class capabilities. The other vehicles in the graphic are not essential for the execution of tests of this situation.



Source: FHWA.

Figure 14. Illustration. Traffic-Incident Management situational layout.

Operational Needs

Situation 2 is intended to address specific operational user needs, as shown in table 8 through table 11.

Table 8. Operational needs for TIM.

Operational Need Identifier	Operational Needs
TIM-N1.01	Nonemergency vehicles move out of the way of emergency vehicles safely and quickly.
TIM-N1.02	Systems gather, integrate, process, and disseminate data.

Table 9. TIM—operational needs for ADS-equipped vehicles.

Operational Need Identifier	Operational Needs for ADS-Equipped Vehicles
TIM-N1.03	Location and speed information from other ADS-equipped vehicles near the first-responder vehicle equipped with ADS.
TIM-N1.04	Location and speed information from first-responder vehicles equipped with ADS near other ADS-equipped vehicles.
TIM-N1.05	Trajectory information from first-responder vehicles equipped with ADS.
TIM-N1.06	Ability to detect vehicles incapable of cooperating with other vehicles.

Table 10. TIM—operational need for non-ADS-equipped vehicles (human driver).

Operational Need Identifier	Operational Need for Non-ADS-Equipped Vehicles (Human Driver)
TIM-N1.07	Visual and audio alerts from approaching first-responder vehicles.

Table 11. TIM—operational needs for TMS.

Operational Need Identifier	Operational Needs for TMS
TIM-N1.08	Gather and process data from ITS devices and ADS-equipped vehicles to monitor current traffic conditions.
TIM-N1.09	Provide traffic and routing information to first-responder vehicles.

Stakeholders and Entities

Researchers can execute the operational situation using several vehicles. The focus of CARMA is on Automation Level 3 or higher and Cooperation Class B capabilities or higher, even though under real-world conditions, other vehicles will also be encountered that will be equipped with lower Automation Levels and Cooperation Classes. The following stakeholders and entities, and their associated minimum vehicle configurations, should be considered when executing this operational situation within CARMA. The rear vehicle is the second vehicle on the through lanes, and the front vehicle is the leading vehicle.

- Test vehicle (vehicle in right lane):
  - ADS vehicle with Automation Level 3 and Cooperation Class B.
- Vehicle 1 (rear) in left lane:
  - ADS vehicle with Automation Level 3 and Cooperation Class B.
- Vehicle 2 (front) in left lane:
  - ADS vehicle with Automation Level 3 and Cooperation Class B.

Another stakeholder is the TMS operator (or software package) that will monitor the positions of each vehicle for recording and storage purposes. This situation does not include any field-device equipment that needs to be managed; therefore, the TMS operator is passive in this situation. If an RSU is used for the communications, then the TMS will need to monitor the communications associated with the RSU.

User-Oriented Operational Description

Concept Diagram

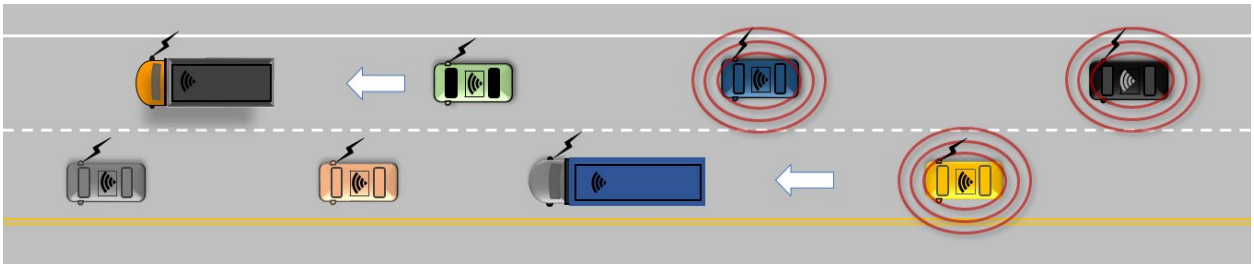
Priority situation 2 includes several ADS-equipped vehicle travel areas—advanced warning/notification, transition, activity, and termination—that are explained in detail in the following sections. The priority situation concepts include an overview diagram for each ADS-equipped vehicle travel area, a description, and a table that shows how vehicles with different Automation Levels and Cooperation Classes would react and respond within each travel area of the situation shown in figure 8.

For the following descriptions of ADS-equipped vehicle travel areas used within CARMA, researchers assumed that the involved vehicles support at least Cooperation Class B capabilities.

Advanced Warning/Notification Vehicle Travel Area

Within the advanced warning/notification area, ADS-equipped vehicles travel along a two-lane roadway. The vehicles receive a broadcast notifying that an ADS-equipped first-responder vehicle is approaching from the rear requesting all vehicles in front move to the outside of their respective lanes (i.e., vehicles in the left lane move to the left and vehicles in the right lane move to the right) to drive slowly and provide an emergency lane for the first-responder vehicle. The ADS-equipped first-responder vehicle could also request that all vehicles move to the right or to the left as far as possible. The information from the emergency vehicle includes location, speed, heading, and the request to move downstream vehicles out of the way. Figure 15 shows a layout of the notification travel area.

Each ADS-equipped vehicle on the two-lane roadway receiving a notification determines, based on its own location, its speed and heading, the direction it will have to move (i.e., vehicles in the left lane move to the left and vehicles in the right lane move to the right) to accommodate the first-responder vehicle, and the approach time of the first-responder vehicle. In this situation, all vehicles on the two-lane roadway will be affected.



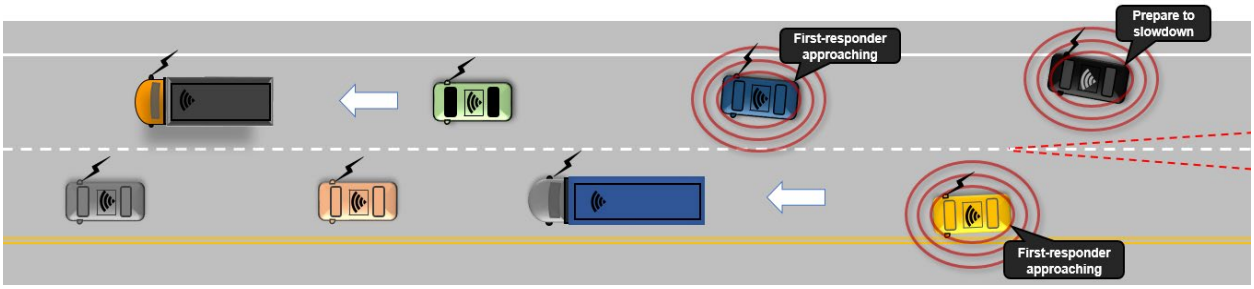
Source: FHWA.

Figure 15. Illustration. TIM—ADS-equipped vehicles receiving a notification.

Vehicle Travel Transition Area

Within the transition area, ADS-equipped vehicles drive on the roadway, receive data from the approaching first-responder vehicle, and prepare to move out of the way, as shown in figure 16. The vehicles also broadcast to each other about their intentions if suitably equipped. This information includes location, speed, heading, as well as path-intention data for the direction each vehicle will take.

Each ADS-equipped vehicle on the two-lane roadway receiving a notification determines, based on its own location, its speed and heading, the direction it will have to move (i.e., vehicles in the left lane move to the left and vehicles in the right lane move to the right), and the approach time of the first-responder vehicle. In this situation, all vehicles on the two-lane roadway will be affected. Vehicles capable of Cooperation Class C exchange data to coordinate the maneuvers each vehicle is executing.

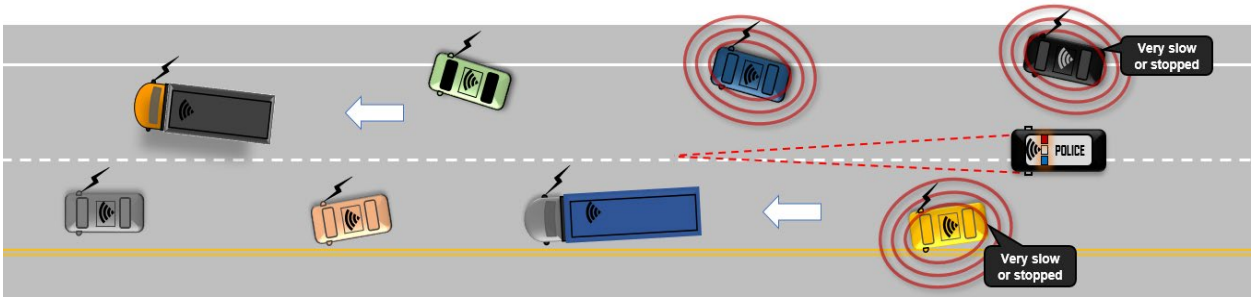


Source: FHWA.

Figure 16. Illustration. TIM—vehicle transition area.

Vehicle Travel Activity Area

Within the activity area (figure 17), ADS-equipped vehicles on the two-lane highway have moved out of the way (i.e., vehicles in the left lane moved to the left and vehicles in the right lane moved to the right) and move slowly or have stopped. They broadcast their current locations as well as their intended-path information to each other and to the first-responder vehicle. The intended-path information includes location, speed, heading, and brake status for the vehicles in the mainline lanes that have slowed or are slowing down or stopped as well as path predictions from each vehicle and the first-responder vehicle.



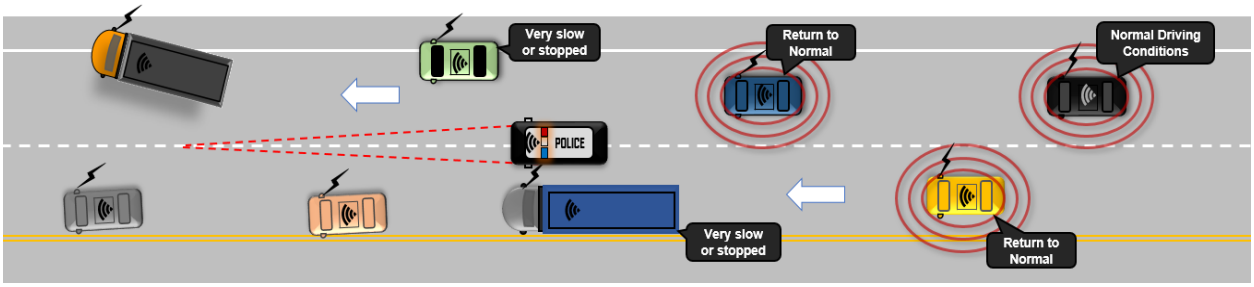
Source: FHWA.

Figure 17. Illustration. TIM—vehicle activity area.

Vehicle Travel Termination Area

Within the termination area, the first-responder vehicle passes ADS-equipped vehicles within the two-lane roadway and traffic returns to normal operation along the roadway, as shown in figure 18. Normal operations will include coordination among the vehicles to determine the sequences and accelerations by each vehicle.

ADS-equipped vehicles in the two-lane roadway must receive data from the ADS-equipped first-responder vehicle to indicate that it is passing each specific ADS-vehicle as it passes.



Source: FHWA.

Figure 18. Illustration. TIM—termination area.

Trigger to Invoke Situation for Vehicles Moving Out of the Way of an ADS-equipped Emergency/First Responder Vehicle

Priority situation 2 is triggered by the ADS-equipped first-responder vehicle when approaching other ADS-equipped vehicles downstream on the two-lane roadway. The following indicators are designated as triggers to invoke responses of mainline vehicles:

- Broadcast by approaching ADS-equipped first-responder vehicle.
- Activation of flashing lights and sirens on the first-responder vehicle intending to merge onto the highway (this is not a CARMA consideration).

All maneuvers by vehicles in the two-lane roadway in front of the ADS-equipped first-responder vehicle are considered reactions to the approaching first-responder vehicle. These maneuvers include moving to the shoulders and slowing down or stopping on the nearest shoulder to create the first-responder vehicle corridor.

Requirements for Vehicles Moving out of the Way of an ADS-Equipped Emergency/First-Responder Vehicle

The requirements to address priority situation 2 and to fulfill the stated user-operational needs are defined in table 12.

Table 12. Requirements for vehicles moving out of the way of an ADS-equipped emergency/first-responder vehicle.

Functional Requirement Identifier	Functional Requirement	Applicable to CARMA
TIM-R1.01	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall provide for the capability to avoid crashes with other vehicles (vehicles with or without Cooperation Class capabilities) prior to, during, and after completion of the move-out-of-the-way maneuver. Communications shall be possible approximately every ⅒ s.	Yes, Cooperation Class B and higher
BT-R1.02	See table 6 for the same requirement FR ID number.	Yes, Cooperation Class B and higher
BT-R1.03	See table 6 for the same requirement FR ID number.	Yes, Cooperation Class B and higher
BT-R1.04	See table 6 for the same requirement FR ID number.	Yes, Cooperation Class B and higher
TIM-R1.02	An ADS-equipped first-responder vehicle with at least Cooperation Class B capabilities shall be able to broadcast a request to move out of the way to other ADS-equipped vehicles with at least Cooperation Class B capabilities within the first responder vehicle's short-range communications approximately every ⅒ s.	Yes, Cooperation Class B and higher
TIM-R1.03	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to receive, decode, process, analyze, and react to a request to move out of the way from ADS-equipped first-responder vehicles with at least Cooperation Class B capabilities within the vehicle's short-range communications approximately every ⅒ s.	Yes, Cooperation Class B and higher
TIM-R1.04	An ADS-equipped first-responder vehicle with at least Cooperation Class B capabilities shall be able to send the geofenced area around it to indicate the move-out-of-the-way request and lane request to the CARMA Cloud℠ approximately every 1 s.	Yes, Cooperation Class B and higher
TIM-R1.05	CARMA Cloud shall be able to broadcast the first-responder vehicle's geofencing area to the physical geofenced area approximately every 1 s.	Yes
TIM-R1.06	A request to move out of the way shall include the following: • Projected path for the next 30 s (in front of first-responder vehicle from vehicle position on the way to incident site). • Geofenced area in front of the first-responder vehicle to which the move-out-of-the-way request applies. • Time stamp of when message was first sent.	Yes
TIM-R1.07	An ADS-equipped first-responder vehicle with at least Cooperation Class B capabilities shall be able to broadcast a request to turn off the geofence to other ADS-equipped vehicles with at least Cooperation Class B capabilities within the ADS-equipped first-responder vehicle's short-range communications approximately every 1 s.	Yes, Cooperation Class B and higher
TIM-R1.08	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to receive, decode, process, analyze, and react to a request to turn off the geofence from vehicles with at least Cooperation Class B capabilities within the ADS-equipped vehicle's short-range communications approximately every 1 s.	Yes, Cooperation Class B and higher

Functional Requirement Identifier	Functional Requirement	Applicable to CARMA
BT-R1.05	See table 6 for the same requirement FR ID number.	Optional, Cooperation Class B and higher
BT-R1.06	See table 6 for the same requirement FR ID number.	Optional, Cooperation Class B and higher
TIM-R1.09	An ADS-equipped first-responder vehicle with at least Cooperation Class B capabilities shall be able to broadcast a request to move out of the way to other ADS-equipped vehicles with at least Cooperation Class B capabilities within its long-range communications approximately every ⅒ s.	Optional, Cooperation Class B and higher
TIM-R1.10	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to receive, decode, process, analyze, and react to a request to move out of the way from ADS-equipped first-responder vehicles with at least Cooperation Class B within its long-range communications approximately every ⅒ s.	Optional, Cooperation Class B and higher
TIM-R1.11	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to broadcast its driving path for the vehicle's previous one minute of travel approximately every 1 s.	No
TIM-R1.12	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to broadcast its intended future driving path for at least the next 15 s approximately every 3 s.	Yes
TIM-R1.13	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to interpret received intentions to create a first-responder emergency corridor (i.e., vehicles in the left lane moved to the left and vehicles in the right lane moved to the right) and process these intentions in conjunction with the received locations, speeds, headings, and brake status from other ADS-equipped vehicles with Cooperation Class A capabilities or higher.	Yes
TIM-R1.14	An ADS-equipped vehicle with Cooperation Class C capabilities shall be able to send and receive, decode, process, analyze, and use detailed intention data including ACKs and NAKs when cooperating with other nonemergency ADS-equipped vehicles with cooperation Class C capabilities during the move-over driving process.	Yes
TIM-R1.15	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to generate and send a NAK to the broadcasting first-responder vehicle within its short-range communications approximately every 1 s if it cannot move out the way of the first-responder vehicle.	Yes
TIM-R1.16	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall, upon receipt of move-over intention indications, process this information to move out of the first-responder vehicle's path and find its own space on the road.	Yes
TIM-R1.17	An ADS-equipped first-responder vehicle with at least Cooperation Class A capabilities approaching other downstream vehicles shall be able to determine that downstream vehicles of all Cooperation Classes (no cooperative automation and higher) are moving out of the way.	Yes
TIM-R1.18	An ADS-equipped vehicle shall be able to use onboard sensors to detect the location, speed, and heading at suitable sensing intervals of vehicles not equipped with ADS in its vicinity.	Yes
TIM-R1.19	An ADS-equipped vehicle shall be able to detect the turn signal status of a vehicle without ADS (without cooperation class capabilities) (assuming there is a clear line of sight).	No

Functional Requirement Identifier	Functional Requirement	Applicable to CARMA
BT-R1.16	See table 6 for the same requirement FR ID number.	Optional
TIM-R1.20	An ADS-equipped first-responder vehicle with at least Cooperation Class B capabilities shall be able to determine that it has passed other vehicles and broadcast to other ADS-equipped vehicles with at least Cooperation Class B capabilities within its short-range communications approximately every 1 s that the request to move out of the way has been rescinded.	Yes, Cooperation Class B and higher
TIM-R1.21	Any ADS-equipped and non-ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use the notification from the ADS-equipped first-responder vehicle that it has passed the ADS-equipped vehicle and use that information to determine how it can safely and efficiently resume its previous travel.	Yes, Cooperation Class B and higher
TIM-R1.22	An ADS-equipped first-responder vehicle with at least Cooperation Class B capabilities shall be able to determine that it has passed other vehicles and broadcast to other ADS-equipped vehicles with at least Cooperation Class B within its long-range communications range approximately every 1 s that the request to move out of the way has been rescinded.	Optional
TIM-R1.23	A TMS shall be able to receive aggregated data (e.g., minimum location, speed, heading, and brake status) from each ADS-equipped vehicle with at least Cooperation Class A capabilities in a specified area. Communications shall be possible approximately every 1 s via short- or long-range communications infrastructure to the TMS.	Yes

ACK = acknowledgment; FR ID = functional requirement identification.

Performance Metrics

Key performance metrics for monitoring and evaluating operations during execution of this situation, some of which were adapted from *A Framework for Automated Driving System Testable Cases and Scenarios*, should include the following:

- Disengagements—occurrence frequency when safety drivers deactivate the ADS feature being tested and take manual control of the vehicles (Thorn et al. 2018).
- Speed changes—changes in vehicle speeds above or below a specified threshold in response to interactions between ADS-equipped vehicles and an ADS-equipped emergency vehicle (i.e., reductions in speeds by the vehicles moving out of the way and reductions/maintenance of the emergency speeds).
- Move-over time—time for vehicles to safely move out of the way of the ADS-equipped emergency vehicle and slow down or stop after receiving the intent or trajectory information from the ADS-equipped emergency vehicle.
- Data exchanges during negotiation (Cooperation Class C)—capture all data exchanges between two Cooperation Class C ADS-equipped vehicles to determine whether the maneuver negotiations took place as designed. The data exchanges include the following data types:
  - Total duration of negotiation process.
  - Frequency of negotiation success/failure (NAKs from neighboring vehicles).
  - Number of attempts before a plan is accepted by all affected neighbors.
  - Message latency. The time difference between message origination on the emergency vehicle to vehicle A's reading of the message. The latency time includes the time to compose the message, sending it from the emergency vehicle's guidance computer to

its OBU, the queuing time on its OBU, the radio transmission from the emergency vehicle to vehicle A, the message constitution and queueing on vehicle A's OBU, sending it from vehicle A's OBU to vehicle A's guidance computer, and the time for vehicle A's decomposition and reading of the message.

Requirements Traceability Matrix for TIM Operational Needs and Functional Requirements

Table 13 traces the relationship between operational needs and functional requirements.

Table 13. Requirements traceability matrix for vehicles moving out of the way of an ADS-equipped emergency/first-responder vehicle.

Operational Needs Identifier	Operational Need	Functional Requirement Identifier	Functional Requirement
TIM-N1.01	Nonemergency vehicles move out of the way of emergency vehicles safely and quickly.	TIM-R1.01	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall provide for the ability to avoid crashes with other vehicles (vehicles with or without cooperation class capabilities) prior to, during, and after completion of the move-out-of-the-way maneuver. Communications shall be possible approximately every ⅒ s.
TIM-N1.02	Gather, integrate, process, and disseminate data.	BT-R1.02	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to broadcast its location, speed, heading, and brake status approximately every ⅒ s.
TIM-N1.02	Gather, integrate, process, and disseminate data.	BT-R1.03	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use locations, speeds, and headings from other ADS-equipped vehicles with at least Cooperation Class A capabilities within its short-range communications approximately every ⅒ s.
TIM-N1.02	Gather, integrate, process, and disseminate data.	BT-R1.04	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use braking status from other ADS-equipped vehicles with at least Cooperation Class A capabilities within its short-range communications approximately every ⅒ s.
TIM-N1.02	Gather, integrate, process, and disseminate data.	TIM-R1.02	An ADS-equipped first-responder vehicle with at least Cooperation Class B capabilities shall be able to broadcast a request to move out of the way to other ADS-equipped vehicles with at least Cooperation Class B capabilities within its short-range communications approximately every ⅒ s.
TIM-N1.02	Gather, integrate, process, and disseminate data.	TIM-R1.03	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to receive, decode, process, analyze, and react to a request to move out of the way from ADS first-responder vehicles with at least Cooperation Class B capabilities within its short-range communications approximately every ⅒ s.

Operational Needs Identifier	Operational Need	Functional Requirement Identifier	Functional Requirement
TIM-N1.02	Gather, integrate, process, and disseminate data.	TIM-R1.04	An ADS-equipped first-responder vehicle with at least Cooperation Class B capabilities shall be able to send the geofenced area around it that indicates the move-out-of-the-way direction and lane request to CARMA Cloud approximately every 1 s.
TIM-N1.02	Gather, integrate, process, and disseminate data.	TIM-R1.05	CARMA Cloud shall be able to broadcast the first-responder vehicle's geofencing area to the physical geofenced area approximately every 1 s.
TIM-N1.02	Gather, integrate, process, and disseminate data.	TIM-R1.06	A move-out-of-the-way request shall include the following: • Projected path for the next 30 s (the path in front of first-responder vehicle from vehicle position on the way to incident site). • Geofenced area in front of the first-responder vehicle to which the move-out-of-the-way request applies. • Time stamp of when message was first sent.
TIM-N1.02	Gather, integrate, process, and disseminate data.	TIM-R1.07	An ADS-equipped first-responder vehicle with at least Cooperation Class B capabilities shall be able to broadcast a request to turn off the geofence to other ADS-equipped vehicles with at least Cooperation Class B capabilities within its short-range communications approximately every 1 s.
TIM-N1.02	Gather, integrate, process, and disseminate data.	TIM-R1.08	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to receive, decode, process, analyze, and react to a request to turn off the geofence from ADS-equipped vehicles with at least Cooperation Class B capabilities within the ADS-equipped vehicle's short-range communications approximately every 1 s.
TIM-N1.02	Gather, integrate, process, and disseminate data.	TIM-R1.09	An ADS-equipped first-responder vehicle with at least Cooperation Class B capabilities shall be able to broadcast a move-out-of-the-way request to other ADS-equipped vehicles with at least Cooperation Class B capabilities within its long-range communications approximately every ⅒ s.
TIM-N1.02	Gather, integrate, process, and disseminate data.	TIM-R1.10	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to receive, decode, process, analyze, and react to a request to move out of the way from ADS-equipped first-responder vehicles with at least Cooperation Class B within its long-range communications approximately every ⅒ s.
TIM-N1.02	Gather, integrate, process, and disseminate data.	TIM-R1.11	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to broadcast its driving path for the previous 1 minute of travel approximately every 1 s.
TIM-N1.02	Gather, integrate, process, and disseminate data.	TIM-R1.12	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to broadcast its intended future driving path for at least the next 15 s approximately every 3 s.

Operational Needs Identifier	Operational Need	Functional Requirement Identifier	Functional Requirement
TIM-N1.03	Location and speed information from other ADS-equipped vehicles near ADS-equipped first-responder vehicles.	BT-R1.02	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to broadcast its location, speed, heading, and brake status approximately every ⅒ s.
TIM-N1.03	Location and speed information from other ADS-equipped vehicles near ADS-equipped first-responder vehicles.	BT-R1.03	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use locations, speeds, and headings from other ADS-equipped vehicles with at least Cooperation Class A capabilities within its short-range communications approximately every ⅒ s.
TIM-N1.03	Location and speed information from other ADS-equipped vehicles near ADS-equipped first-responder vehicles.	BT-R1.05	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use locations, speeds, and headings from other ADS-equipped vehicles with at least Cooperation Class A via long-range communications within a configurable geofenced area approximately every ⅒ s.
TIM-N1.04	Location and speed information from ADS-equipped first-responder vehicles near other ADS-equipped vehicles.	BT-R1.02	An ADS-equipped with at least Cooperation Class A capabilities shall be able to broadcast its location, speed, heading, and brake status approximately every ⅒ s.
TIM-N1.04	Location and speed information from ADS-equipped first-responder vehicles near other ADS-equipped vehicles.	BT-R1.03	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use locations, speeds, and headings from other ADS-equipped vehicles with at least Cooperation Class A within its short-range communications approximately every ⅒ s.
TIM-N1.04	Location and speed information from ADS-equipped first-responder vehicles near other ADS-equipped vehicles.	BT-R1.05	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use locations, speeds, and headings from other ADS-equipped vehicles with at least Cooperation Class A capabilities via long-range communications within a configurable geofenced area approximately every ⅒ s.
TIM-N1.05	Trajectory information from ADS-equipped first-responder vehicle.	TIM-R1.09	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to broadcast a move-out-of-the-way request to other ADS-equipped vehicles with at least Cooperation Class B capabilities within its long-range communications approximately every ⅒ s.
TIM-N1.05	Trajectory information from ADS-equipped first-responder vehicle.	TIM-R1.17	An ADS-equipped first-responder vehicle with at least Cooperation Class A capabilities approaching other downstream vehicles shall be able to determine that downstream vehicles of all Cooperation Classes (no cooperative automation and higher) are moving out of the way.

Operational Needs Identifier	Operational Need	Functional Requirement Identifier	Functional Requirement
TIM-N1.05	Trajectory information from ADS-equipped first-responder vehicle.	TIM-R1.20	An ADS-equipped first-responder vehicle with at least Cooperation Class B capabilities shall be able to determine that it has passed other vehicles and broadcast to these other ADS-equipped vehicles with at least Cooperation Class B capabilities within its short-range communications approximately every 1 s that the move-out-of-the-way request has been rescinded.
TIM-N1.06	Detect vehicles incapable of cooperating with other vehicles.	TIM-R1.18	An ADS-equipped vehicle shall be able to use onboard sensors to detect the location, speed, and heading at suitable sensing intervals of non-ADS-equipped vehicles.
TIM-N1.06	Ability to detect vehicles incapable of cooperating with other vehicles.	TIM-R1.19	An ADS-equipped vehicle shall be able to detect the turn-signal status of a non-ADS-equipped vehicle without cooperation class capabilities (assuming there is a clear line of sight).
TIM-N1.06	Detect vehicles incapable of cooperating with other vehicles.	BT-R1.16	An ADS-equipped vehicle shall have a means to visually display to the driver of another ADS-equipped vehicle the location of other vehicles about which it has information.
TIM-N1.07	Visual and audio alerts from approaching first-responder vehicles.	TIM-R1.13	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to interpret received intentions to create a first-responder emergency corridor (vehicles in the left lane move to the left and vehicles in the right lane move to the right) and process these intentions in conjunction with the received locations, speeds, headings, and brake status from other ADS-equipped vehicles with Cooperation Class A capabilities or higher.
TIM-N1.07	Visual and audio alerts from approaching first-responder vehicles.	TIM-R1.14	An ADS-equipped vehicle with Cooperation Class C capabilities shall be able to send and receive, decode, process, analyze, and use detailed intention data, including ACKs and NAKs when cooperating with other nonemergency ADS-equipped vehicles with Cooperation Class C capabilities during the move-over driving process.
TIM-N1.07	Visual and audio alerts from approaching first-responder vehicles.	TIM-R1.15	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to generate and send a NAK to the broadcasting first-responder vehicle within its short-range communications approximately every 1 s if it cannot move out the way of the first-responder vehicle.
TIM-N1.07	Visual and audio alerts from approaching first-responder vehicles.	TIM-R1.16	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall, upon receipt of move-over intention indications, process this information to move out of the first-responder vehicle's path and find its own space on the road.

Operational Needs Identifier	Operational Need	Functional Requirement Identifier	Functional Requirement
TIM-N1.08	Gather and process data from ITS devices and ADS-equipped vehicles to monitor current traffic conditions.	TIM-R1.21	Any ADS-equipped and non-ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use the notification from the ADS-equipped first-responder vehicle that it has passed the ADS-equipped vehicle and use that information to determine how it can safely and efficiently resume its previous travel.
TIM-N1.08	Gather and process data from ITS devices and ADS-equipped vehicles to monitor current traffic conditions.	TIM-R1.22	An ADS-equipped first-responder vehicle with at least Cooperation Class B capabilities shall be able to determine that it has passed other vehicles and broadcast to other ADS-equipped vehicles with at least Cooperation Class B capabilities within its long-range communications approximately every 1 s that the request to move out of the way has been rescinded.
TIM-N1.08	Gather and process data from ITS devices and ADS-equipped vehicles to monitor current traffic conditions.	BT-R1.17	A TMS shall be able to receive aggregated data (e.g., location, speed, heading, and brake status) from each ADS-equipped vehicle with at least Cooperation Class A capabilities in a specified area. Communications shall be possible approximately every 1 s via short- or long-range communications infrastructure to the TMS.
TIM-N1.09	Provide traffic and routing information to first-responder vehicles.	TIM-R1.23	A TMS shall be able to receive aggregated data (e.g., location, speed, heading, and brake status) from each ADS-equipped vehicle with at least Cooperation Class A capabilities in a specified area. Communications shall be possible every 1 s via short- or long-range communications infrastructure to the TMS.

ACK = acknowledgment.

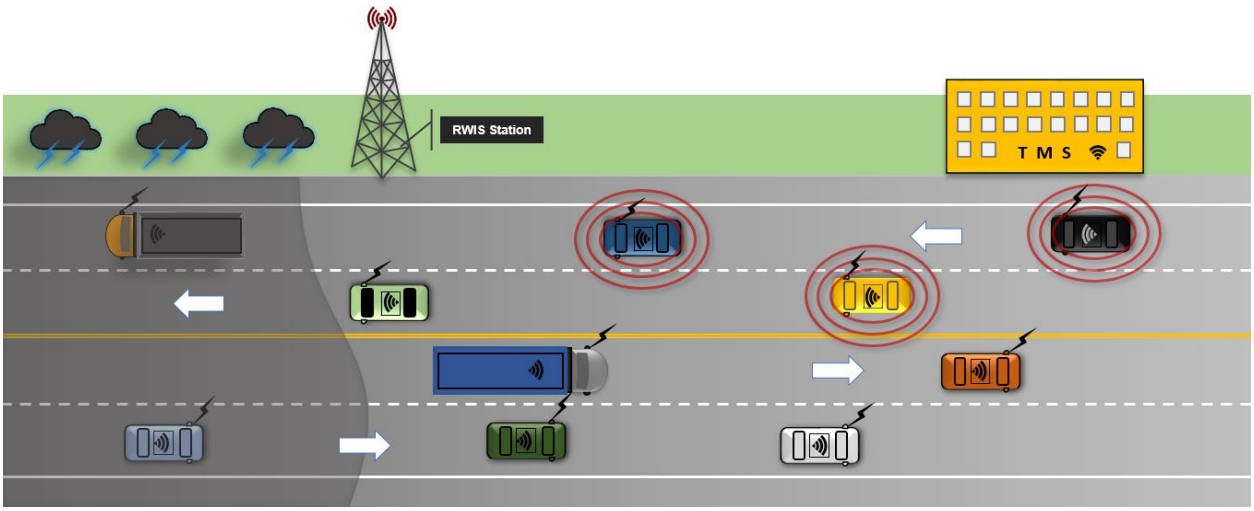
CHAPTER 5. USE CASE: RWM

PRIORITY SITUATION 3 TREATMENT: ADS-EQUIPPED VEHICLES SLOW DOWN/INCREASE GAP WHEN PASSING OVER WET PAVEMENT

The subject of this situational analysis is an ADS feature with a specified ODD that includes operation of ADS-equipped vehicles passing over wet pavement as safely as possible. Researchers sought at least one vehicle equipped with the appropriate onboard sensors to detect weather conditions (e.g., wet pavement, ice, and black ice) on the roadway, as well as surface temperatures, which the vehicle can broadcast to other vehicles in its vicinity. CARMA may have at least one vehicle that can interface with the vehicle's Controller Area Network bus to obtain, process, and transmit windshield wiper status and antilock braking system (ABS) status. The roadway is populated by vehicles of different Automation Levels and Cooperation Classes.

ADS-equipped vehicles travel through the travel areas of advanced warning/notification, transition, activity, and termination. These travel areas are defined in chapter 2.

Priority situation 3 involves several vehicles traveling along a roadway with two lanes in each direction approaching a section with wet pavement. The TMS receives information from a road weather information system (RWIS) about wet conditions in the area. The TMS creates a geofence around the area to transmit this information to ADS-equipped vehicles traveling in both directions. The vehicle with onboard weather-sensing equipment also transmits the wet-pavement information to vehicles that are upstream and traveling in the opposite direction. The vehicles receiving the information slow down and increase the gap between vehicles, called headway, to safely pass the wet pavement. A TMS can only provide generic information (e.g., reduced speed recommendations, speed limits, and recommended headways) based on weather data. The vehicle knows its own conditions (e.g., condition of brakes, loads/weight of vehicle), which are factors that might be used to further decrease speeds and increase headways for safe vehicle operation. This specific aspect is not currently considered in CARMA but might need to be considered in the future. The situational layout is depicted in figure 19. The situation includes vehicles with different cooperation class capabilities shown in circles in the graphic. The other vehicles in the graphic are not essential for the execution of tests of this situation.



Source: FHWA.

Figure 19. Illustration. Road Weather Management situational layout.

Operational Needs

Situation 3 is intended to address specific operational user needs, as presented in table 14 through table 17.

Table 14. Operational needs for RWM.

Operational Need Identifier	Operational Need
RWM-N1.01	Safely travel along a roadway impacted by adverse weather.
RWM-N1.02	Gather, integrate, process, and disseminate road weather information.

Table 15. RWM—operational needs for ADS-equipped vehicle systems.

Operational Need Identifier	Operational Needs for ADS-Equipped Vehicle Systems
RWM-N1.03	Identify location and speed information from vehicles near the ADS-equipped vehicle.
RWM-N1.04	Accept and process road weather information (weather data, reduced speed limits, and recommended headways) to adjust speed and headway spacing accordingly.
RWM-N1.05	Transmit road weather information to other vehicles.
RWM-N1.06	Detect vehicles incapable of cooperating with other vehicles.

Table 16. RWM—operational needs for non-ADS equipped vehicles (human driver).

Operational Need Identifier	Operational Needs for Non-ADS (Human Driver)
RWM-N1.07	Visual alerts about adverse-weather conditions from ITS devices or radio broadcasts.
RWM-N1.08	Information on acceptable speed limits to safely navigate roadways affected by adverse-weather conditions.

Table 17. RWM—operational needs for TMS.

Operational Need Identifier	Operational Needs for Traffic Management Service
RWM-N1.09	Determine pavement temperature and presence of water, snow, or ice on the roadway.
RWM-N1.10	Provide road weather condition information to ADS-equipped vehicles in a geofenced area.
RWM-N1.11	Provide road weather condition response suggestions (reduced speed limits and recommended headways) to ADS-equipped vehicles in a geofenced area.
RWM-N1.12	Gather and process data from ITS devices and ADS-equipped vehicles to monitor current traffic conditions.

Stakeholders and Entities

Researchers can execute the operational situation using several vehicles. The focus of CARMA is on Automation Level 3 or higher and Cooperation Class B capabilities or higher, but under real-world conditions, other vehicles might also be encountered that will only be equipped with lower Automation Levels and Cooperation Classes. The following stakeholders and entities and their associated minimum vehicle configurations should be considered when executing this operational situation within the CARMA program.

- Weather detection sensor-equipped vehicle (vehicle driving in the opposite direction):
  - ADS vehicle with Automation Level 3 and Cooperation Class B.
- Vehicle 1 (front):
  - ADS vehicle with Automation Level 3 and Cooperation Class B.
- Vehicle 2 (rear):
  - ADS vehicle with Automation Level 3 and Cooperation Class B.

Another stakeholder is the TMS operator (or software package), that will monitor the positions of each vehicle for recording and storage purposes. The TMS will also receive the data from the weather detection sensor-equipped vehicle as well as from roadside weather stations, which it will aggregate and broadcast via short- or long-range communications media. If an RSU is used for the communications, then the TMS will monitor the communications associated with the RSU and send weather information to the RSU for local rebroadcast.

User-Oriented Operational Description

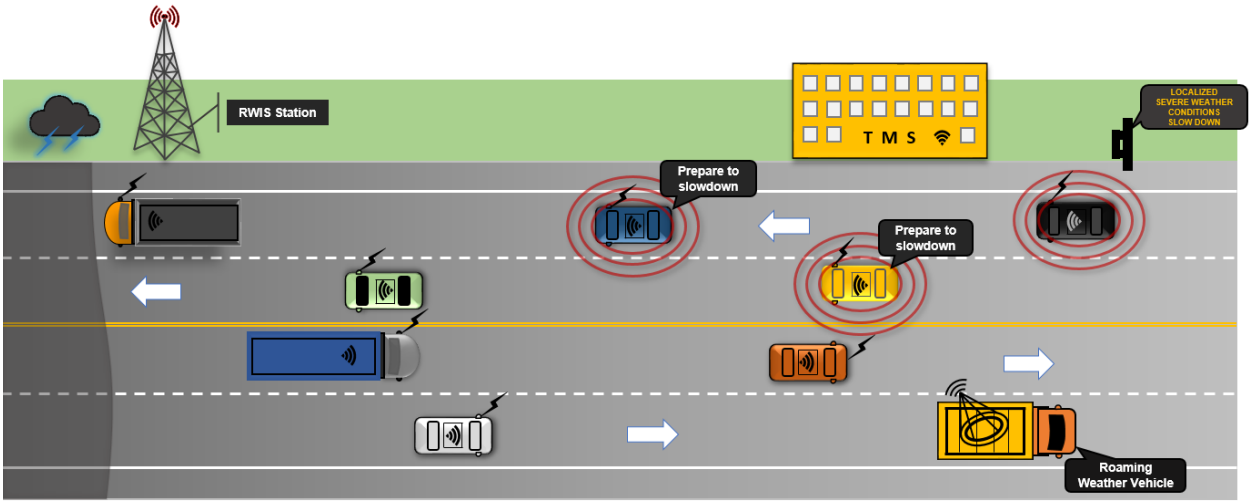
Concept Diagram

Situation 3 includes several ADS-equipped vehicle travel areas—advanced warning/notification, transition, activity, and termination—that are explained in detail and are suitable for this situation. The concepts include an overview diagram for each ADS-equipped vehicle travel area, a description, and a table that shows how vehicles with different Automation Levels and Cooperation Classes would react and respond within each travel area associated with this situation.

For the following descriptions of ADS vehicle travel areas used within CARMA, researchers assumed that the involved vehicles support at least Cooperation Class B capabilities.

Advanced Warning/Notification Vehicle Travel Area

Within the advanced warning/notification vehicle travel area, the ADS-equipped vehicles travel along a two-lane roadway, during which they all receive a broadcast from the TMS with a notification that the downstream area has localized adverse-weather conditions and to be prepared to slow down when approaching the affected area. This is shown in figure 20. The TMS-provided weather data are based both on roadside weather stations and from information from the TMS, which includes a geofenced area (location) at which the RWIS stations and the roaming weather-detection vehicle have detected adverse weather, the type of weather impact, and the request to prepare to slow down to a suggested speed when arriving at the geofenced weather area.



Source: FHWA.

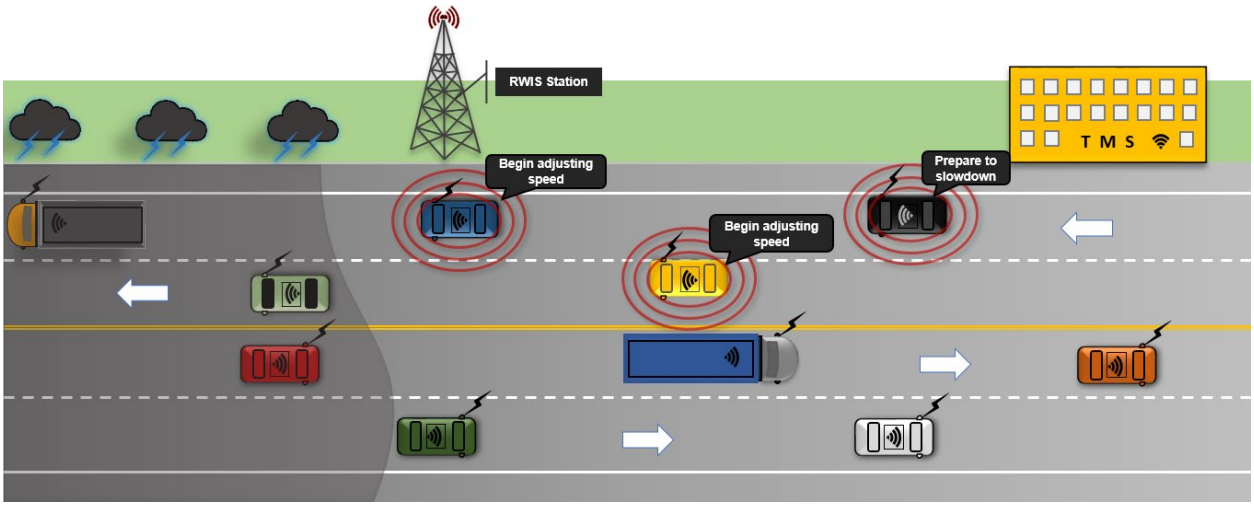
Figure 20. Illustration. RWM—ADS-equipped vehicles receiving a notification.

Vehicle Travel Transition Area

In the transition area, the ADS-equipped vehicles drive along the roadway and continuously receive updates to the weather warning messages from the TMS and are prepared to adjust to the suggested speeds, as shown in figure 21.

Vehicles equipped with weather detection sensors are assumed to arrive at the transition area from the opposite direction of the weather event and to broadcast the observed weather data to the approaching vehicles, just as it did the entire time. These data include the detected start and end points of the adverse-weather area (the approaching vehicles will have to invert this information), the vehicle's speed and heading, as well as the type of weather impact. Within CARMA, a vehicle will provide windshield wiper and ABS status data to emulate a weather event.

Each ADS-equipped vehicle receiving a notification adjusts its speeds to the suggested speeds by the time the vehicle arrives at the start of the geofenced weather-impacted area. In this situation, all vehicles on the roadway will be affected.

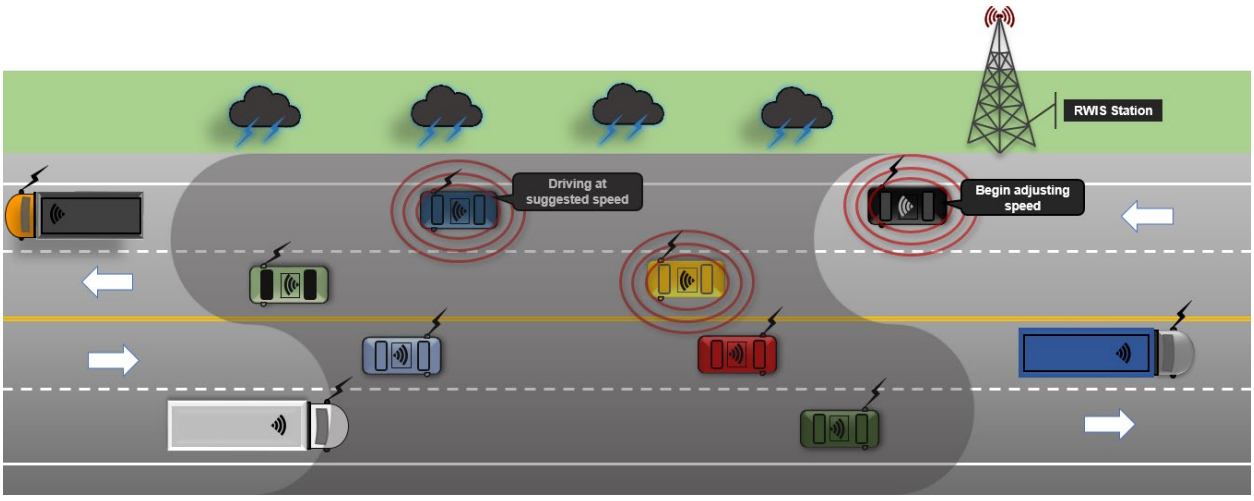


Source: FHWA.

Figure 21. Illustration. RWM—vehicle transition area.

Vehicle Travel Activity Area

Within the activity area, the ADS-equipped vehicles on the highway are moving at the suggested speed but are always prepared to adjust their speed based on their own sensory assessments (e.g., ABS engagement). ADS-equipped vehicles broadcast their current locations, speeds, headings, detected weather data (if applicable), and their intended-path information to other vehicles in both driving directions, the TMS, and the weather-detecting vehicle driving in the opposite direction (if still in range). A layout of the road weather activity area is shown in figure 22.

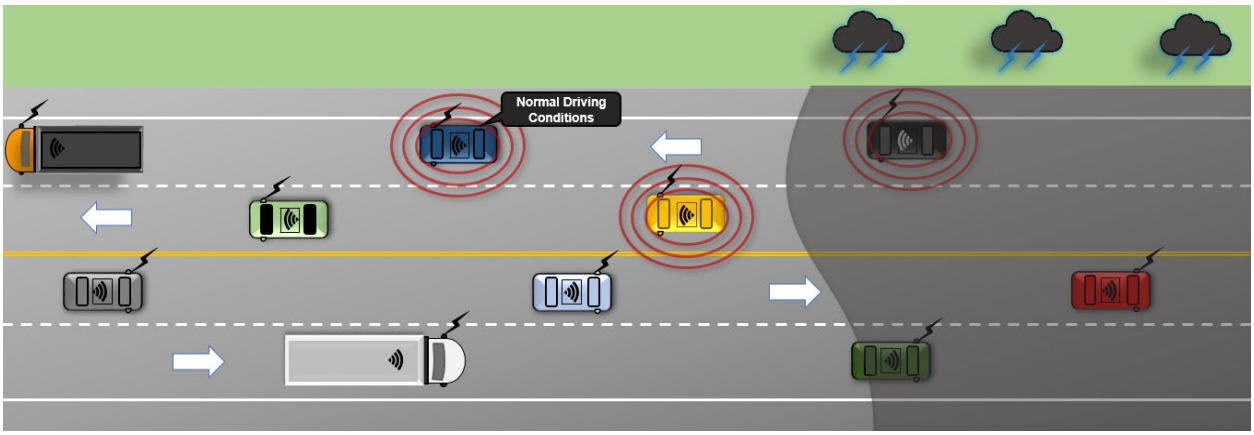


Source: FHWA.

Figure 22. Illustration. RWM—vehicle activity area.

Vehicle Travel Termination Area

Within the termination area, the ADS-equipped vehicles reach the end of the weather-affected area and return to normal operation along the roadway, as shown in figure 23. Returning to normal operation includes increasing driving speeds to safe levels, ultimately up to the posted speed limit. ADS-equipped vehicles are broadcasting their locations, current speeds, heading, and any current weather-detection readings to other ADS-equipped vehicles in both driving directions and the TMS.



Source: FHWA.

Figure 23. Illustration. RWM—termination area.

Trigger to Invoke Situation for ADS-Equipped Vehicles Slowing down and Increasing Gap When Passing over Wet Pavement

Priority situation 3 is triggered by the TMS and the weather-detecting vehicle sending weather warnings and suggested speed data to ADS-equipped vehicles approaching the weather-affected geofenced area. The following indicators are designated as triggers to invoke responses of ADS-equipped vehicles:

- Broadcast by a TMS.
- Broadcast by vehicles equipped with weather-detection sensors driving in the same, or more likely the opposite, direction (within CARMA, a vehicle will provide windshield wiper and ABS status data to emulate a weather event).

All maneuvers by vehicles on the roadway are considered reactions to the received weather data and suggested speeds when driving through the weather-impacted, geofenced area.

Requirements for ADS-Equipped Vehicles Slowing Down and Increasing Gap When Passing Over Wet Pavement

The requirements to address situation 3 and to fulfill the stated user-operational needs are defined in table 18.

Table 18. Requirements and operational needs for ADS-equipped vehicles slowing down and increasing gap when passing over wet pavement.

Functional Requirement Identifier	Functional Requirement	Applicable to CARMA
RWM-R1.01	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall provide for the ability to avoid crashes with other vehicles (vehicles with or without cooperation class capabilities) prior to, during, and after completion of the maneuver. Vehicle adjusts speed and prepares for other adjustments at beginning of weather-event zone. Communications shall be possible approximately every ⅒ s.	Yes, Cooperation Class B and higher
BT-R1.02	See table 6 for the same requirement FR ID number.	Yes, Cooperation Class B and higher
BT-R1.03	See table 6 for the same requirement FR ID number.	Yes, Cooperation Class B and higher.
BT-R1.04	See table 6 for the same requirement FR ID number.	Yes, Cooperation Class B and higher
RWM-R1.02	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to broadcast the windshield-wiper activation and/or ABS-engagement activation to other ADS-equipped vehicles with at least Cooperation Class A within its short-range communications approximately every 1 s.	Yes, Cooperation Class B and higher
RWM-R1.03	An ADS-equipped vehicle with onboard weather-detection equipment and with at least Cooperation Class A capabilities shall be able to broadcast the detected weather data to other ADS-equipped vehicles with at least Cooperation Class A capabilities within its short-range communications approximately every 1 s.	Optional, Cooperation Class B and higher
RWM-R1.04	An ADS-equipped vehicle with onboard weather-detection equipment shall be able to broadcast at a minimum the following weather-related data (if the related sensors are mounted onboard and are functioning properly): • Wet-pavement indication. • Icy-pavement indication. • Black ice on pavement indication. • Weather sensor operational status (failed/operational).	Optional, Cooperation Class B and higher
RWM-R1.05	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and react to the weather data from weather-detection vehicles equipped with ADS with at least Cooperation Class A capabilities within its short-range communications approximately every 1 s.	Yes, Cooperation Class B and higher
RWM-R1.06	A TMS shall be able to broadcast the detected weather data from its connected RWIS to ADS-equipped vehicles with at least Cooperation Class A capabilities within its short-range communications approximately every 5 s.	Yes, Cooperation Class B and higher

Functional Requirement Identifier	Functional Requirement	Applicable to CARMA
RWM-R1.07	A TMS shall be able to broadcast, at a minimum, the following weather-related data (assuming the applicable sensor data are available): • Pavement-surface condition indication. • Precipitation-presence indication. • Icing-conditions indication. • Location indication. • Weather sensor operational status (failed/operational).	Yes
RWM-R1.08	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and react to the weather data from a TMS via short-range communications approximately every 10 s.	Yes, Cooperation Class B and higher
RWM-R1.09	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to broadcast the windshield-wiper activation and/or ABS-engagement activation in near real-time to other ADS-equipped vehicles with at least Cooperation Class A within its long-range communications approximately every 1 s.	Optional, Cooperation Class B and higher
RWM-R1.10	An ADS-equipped vehicle with onboard weather-detection equipment and at least Cooperation Class A capabilities shall be able to broadcast the detected weather data in near real-time to other ADS-equipped vehicles with at least Cooperation Class A capabilities within its long-range communications range approximately every 1 s.	Optional, Cooperation Class B and higher
RWM-R1.11	An ADS-equipped vehicle with onboard weather-detection equipment shall be able to broadcast at a minimum the following weather-related data (assuming the applicable sensor data are available): • Pavement-surface condition indication. • Precipitation-presence indication • Icing-conditions indication. • Location indication. • Weather-sensor operational status (failed/operational).	Yes
RWM-R1.12	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to receive, decode, process, analyze, and react to the weather data from weather-detection vehicles equipped with ADS with at least Cooperation Class B capabilities within its long-range communications approximately every 1 s.	Optional
RWM-R1.13	A TMS shall be able to broadcast the detected weather data to ADS-equipped vehicles with at least Cooperation Class A capabilities within its long-range communications approximately every 10 s.	Optional, Cooperation Class B and higher
RWM-R1.14	A TMS shall be able to broadcast at a minimum the following weather-related data (if the related sensor data are available): • Pavement-surface condition indication. • Precipitation-presence indication. • Icing-conditions indication. • Location indication. • Weather-sensor operational status (failed/operational).	Yes
RWM-R1.15	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to receive, decode, process, analyze, and react to weather data from a TMS via long-range communications approximately every 10 s.	Optional
RWM-R1.16	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to broadcast its driving path for the previous 1 min of travel approximately every 1 s.	No

Functional Requirement Identifier	Functional Requirement	Applicable to CARMA
TIM-R1.12	See table 12 for the same requirement FR ID number.	Yes
RWM-R1.17	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to interpret received intentions to reduce speeds due to weather events and process these intentions in conjunction with the locations, speeds, headings, and brake status received from other ADS-equipped vehicles with Cooperation Class A or higher.	Yes
RWM-R1.18	An ADS-equipped vehicle shall be able to detect a vehicle not equipped with ADS if in detection range.	No
RWM-R1.19	An ADS-equipped vehicle shall have a means to visually display to the driver the location of other vehicles about which it has information.	Optional
RWM-R1.20	A TMS shall be able to continuously broadcast the detected RWIS weather data, including any modifications to the geofenced adverse-weather area approximately every 10 s.	Yes, Cooperation Class B and higher
RWM-R1.21	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use adverse-weather data from a TMS to determine when and where it can safely and efficiently resume its previous travel speeds.	Yes, Cooperation Class B and higher
RWM-R1.22	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use the adverse-weather data from an ADS-equipped vehicle with weather-detection equipment to determine when and where it can safely and efficiently resume its previous travel speeds.	Yes, Cooperation Class B and higher
BT-R1.17	See table 6 for the same requirement FR ID number.	Yes
RWM-R1.23	A TMS shall be able to receive vehicle operations and weather-related data (e.g., locations, speeds, headings, brake status, and available weather data) from an ADS-equipped vehicle with at least Cooperation Class A capabilities in a specified area that can provide weather data. Communications shall be possible approximately every 1 s via short- or long-range communications infrastructure to the TMS.	Yes

FR ID = functional requirement identification.

Performance Metrics

Key performance metrics for monitoring and evaluating operations during execution of situation 3, some of which were adapted from *A Framework for Automated Driving System Testable Cases and Scenarios*, should include the following:

- Separation distances—longitudinal distances between the vehicles in the test. Separation distances are used to determine safe distances and the frequency of infringement of those distances (Thorn et al. 2018).
- Disengagements—occurrence frequency when safety drivers deactivate the ADS feature being tested and take manual control of the vehicles (Thorn et al. 2018).
- Travel speeds driven: Speeds driven by each of the vehicles during the tests will be used to create an accurate picture (playback) for evaluating driving within the vehicle travel areas.
- Deceleration rate—vehicle's change-of-speed rate when approaching the wet pavement (Thorn et al. 2018).

- Weather-content message latency—the time difference between origination of the weather-content message from the TMS to receipt by the vehicle, including time to decompose and read the message.
- Speed changes—changes in speeds of the vehicles greater than (or less than) a specified threshold in response to interactions between ADS-equipped vehicles driving toward the adverse-weather area and an ADS-equipped maintenance vehicle (reduction in speeds by the vehicles reacting to weather information received from the equipped maintenance vehicle).

Requirements Traceability Matrix for Road Weather Management Operational Needs and Functional Requirements

Table 19 traces the relationship between operational needs and functional requirements.

Table 19. Requirements traceability matrix for ADS-equipped vehicles slowing down and increasing gap when passing over wet pavement.

Operational Need Identifier	Operational Need	Functional Requirement Identifier	Functional Requirement
RWM-N1.01	Safely travel along a roadway impacted by adverse weather.	RWM-R1.01	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall provide for the capability to avoid crashes with other vehicles with or without cooperation class capabilities prior to, during, and after completion of the maneuver, Vehicle adjusts speed and prepares for other adjustments at beginning of weather-event zone. Communications shall be possible approximately every ⅒ s.
RWM-N1.02	Gather, integrate, process, and disseminate road weather information.	RWM-R1.02	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to broadcast the windshield-wiper activation and/or ABS-engagement activation to other ADS-equipped vehicles with at least Cooperation Class A within its short-range communications approximately every 1 s.
RWM-N1.02	Gather, integrate, process, and disseminate road weather information.	RWM-R1.03	An ADS-equipped vehicle with, onboard weather-detection equipment and at least Cooperation Class A capabilities shall be able to broadcast the detected weather data to other ADS-equipped vehicles with at least Cooperation Class A within its short-range communications approximately every 1 s.
RWM-N1.02	Gather, integrate, process, and disseminate road weather information.	RWM-R1.04	An ADS-equipped vehicle with onboard weather-detection equipment shall be able to broadcast at a minimum the following weather-related data (if the related onboard sensors are functioning properly): • Wet-pavement indication. • Icy pavement indication. • Black ice on pavement indication. • Weather sensor operational status (failed/operational).

Operational Need Identifier	Operational Need	Functional Requirement Identifier	Functional Requirement
RWM-N1.02	Gather, integrate, process, and disseminate road weather information.	RWM-R1.05	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and react to the weather data from ADS-equipped weather-detection vehicles with at least Cooperation Class A capabilities within its short-range communications approximately every 1 s.
RWM-N1.03	Gather location and speed information from vehicles near the ADS-equipped vehicle.	BT-R1.02	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to broadcast its location, speed, heading, and brake status approximately every ⅒ s.
RWM-N1.03	Gather location and speed information from vehicles near the ADS-equipped vehicle.	BT-R1.03	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use locations, speeds, and headings from other ADS-equipped vehicles with at least Cooperation Class A within its short-range communications range approximately every ⅒ s.
RWM-N1.03	Gather location and speed information from vehicles near the ADS-equipped vehicle.	RWM-R1.16	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to broadcast its driving path for the previous 1 min at approximately every 1 s.
RWM-N1.04	Accept and process road weather information (e.g., weather data, reduced speed limits, and recommended headways) to adjust speed and headway spacing accordingly.	RWM-R1.05	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and react to the weather data from ADS-equipped weather-detection vehicles with at least Cooperation Class A capabilities within its short-range communications approximately every 1 s.
RWM-N1.04	Accept and process road weather information (e.g., weather data, reduced speed limits, and recommended headways) to adjust speed and headway spacing accordingly.	RWM-R1.08	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and react to the weather data from a TMS via short-range communications approximately every 10 s.
RWM-N1.04	Accept and process road weather information (e.g., weather data, reduced speed limits, and recommended headways) to adjust speed and headway spacing accordingly.	RWM-R1.12	An ADS-equipped vehicle with at least ADS vehicle with at least Cooperation Class B capabilities shall be able to receive, decode, process, analyze, and react to the weather data from ADS-equipped weather-detection vehicles with at least Cooperation Class B capabilities within its long-range communications approximately every 1 s.
RWM-N1.04	Accept and process road weather information (e.g., weather data, reduced speed limits, and recommended headways) to adjust speed and headway spacing accordingly.	RWM-R1.15	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to receive, decode, process, analyze, and react to the weather data from a TMS via long-range communications approximately every 10 s.

Operational Need Identifier	Operational Need	Functional Requirement Identifier	Functional Requirement
RWM-N1.04	Accept and process road weather information (weather data, reduced speed limits, and recommended headways) to adjust speed and headway spacing accordingly.	RWM-R1.17	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to interpret received intentions to reduce speeds due to weather events and process these intentions in conjunction with the locations, speeds, headings, and brake status received from other ADS-equipped vehicles with Cooperation Class A capabilities or higher.
RWM-N1.04	Accept and process road weather information (weather data, reduced speed limits, and recommended headways) to adjust speed and headway spacing accordingly.	RWM-R1.21	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use the adverse-weather data from a TMS to determine when and where it can safely and efficiently resume its previous travel speeds.
RWM-N1.04	Accept and process road weather information (weather data, reduced speed limits, and recommended headways) to adjust speed and headway spacing accordingly.	RWM-R1.22	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use the adverse-weather data from an ADS- and weather detection-equipped vehicle to determine when and where it can safely and efficiently resume its previous travel speeds.
RWM-N1.05	Transmit road weather information to other vehicles.	RWM-R1.02	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to broadcast the windshield-wiper activation and/or ABS-engagement activation to other ADS-equipped vehicles with at least Cooperation Class A capabilities within its short-range communications approximately every 1 s.
RWM-N1.05	Transmit road weather information to other vehicles.	RWM-R1.03	An ADS-equipped vehicle with onboard weather-detection equipment and with at least Cooperation Class A capabilities shall be able to broadcast the detected weather data to other ADS-equipped vehicles with at least Cooperation Class A capabilities within its short-range communications range every 1 s.
RWM-N1.05	Transmit road weather information to other vehicles.	RWM-R1.04	An ADS-equipped vehicle with onboard weather-detection equipment shall be able to broadcast at a minimum the following weather-related data (if the onboard sensors are mounted and functioning properly): • Wet-pavement indication. • Icy pavement indication. • Black ice on pavement indication. • Weather sensor operational status (failed/operational).
RWM-N1.05	Transmit road weather information to other vehicles.	RWM-R1.06	A TMS shall be able to broadcast the detected weather data from its connected RWIS to ADS-equipped vehicles with at least Cooperation Class A capabilities within its short-range communications approximately every 5 s.

Operational Need Identifier	Operational Need	Functional Requirement Identifier	Functional Requirement
RWM-N1.05	Transmit road weather information to other vehicles.	RWM-R1.07	A TMS shall be able to broadcast, at a minimum, the following weather-related data (assuming the applicable sensor data are available): • Pavement surface condition indication. • Precipitation presence indication. • Icy conditions indication. • Location indication. • Weather sensor operational status (failed/operational).
RWM-N1.05	Transmit road weather information to other vehicles.	RWM-R1.09	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to broadcast the windshield-wiper activation and/or ABS-engagement activation in near real-time to other ADS-equipped vehicles with at least Cooperation Class A capabilities within its long-range communications approximately every 1 s.
RWM-N1.05	Transmit road weather information to other vehicles.	RWM-R1.10	An ADS-equipped vehicle with onboard weather-detection equipment and at least Cooperation Class A capabilities shall be able to broadcast the detected weather data in near real-time to other ADS-equipped vehicles with at least Cooperation Class A capabilities within its long-range communications approximately every 1 s.
RWM-N1.05	Transmit road weather information to other vehicles.	RWM-R1.11	An ADS-equipped vehicle with onboard weather-detection equipment shall be able to broadcast at a minimum the following weather-related data (assuming the applicable sensor data are available): • Pavement-surface condition indication. • Precipitation presence indication. • Icy conditions indication. • Location indication. • Weather-sensor operational status (failed/operational).
RWM-N1.05	Transmit road weather information to other vehicles.	RWM-R1.13	A TMS shall be able to broadcast detected weather data to ADS-equipped vehicles with at least Cooperation Class A capabilities within its long-range communications approximately every 10 s.
RWM-N1.05	Transmit road weather information to other vehicles.	RWM-R1.14	A TMS shall be able to broadcast at a minimum the following weather-related data (if the related sensor data are available): • Pavement-surface condition indication. • Precipitation presence indication. • Icy conditions indication. • Location indication. • Weather-sensor operational status (failed/operational).
RWM-N1.06	Detect vehicles incapable of cooperating with other vehicles.	RWM-R1.18	An ADS-equipped vehicle shall be able to detect the reduction of speed in a vehicle without ADS if it is in detection range.

Operational Need Identifier	Operational Need	Functional Requirement Identifier	Functional Requirement
RWM-N1.06	Detect vehicles incapable of cooperating with other vehicles.	RWM-R1.19	An ADS-equipped vehicle shall have a means to visually display to the driver the location of other vehicles about which it has information.
RWM-N1.07	Visual alerts about adverse-weather conditions from ITS devices or radio broadcasts.	RWM-R1.02	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to broadcast the windshield-wiper activation and/or ABS-engagement activation to other ADS-equipped vehicles with at least Cooperation Class A capabilities within its short-range communications approximately every 1 s.
RWM-N1.07	Visual alerts about adverse-weather conditions from ITS devices or radio broadcasts.	RWM-R1.04	An ADS-equipped vehicle with onboard weather-detection equipment shall be able to broadcast at a minimum the following weather-related data (if the onboard sensors are mounted and functioning properly): • Wet-pavement indication. • Icy-pavement indication. • Black ice on pavement indication. • Weather sensor operational status (failed/operational).
RWM-N1.07	Visual alerts about adverse-weather conditions from ITS devices or radio broadcasts.	RWM-R1.07	A TMS shall be able to broadcast, at a minimum, the following weather-related data (assuming the applicable sensors data are available): • Pavement-surface condition indication • Precipitation presence indication. • Icy conditions indication. • Location indication. • Weather sensor operational status (failed/operational).
RWM-N1.07	Visual alerts about adverse-weather conditions from ITS devices or radio broadcasts.	RWM-R1.09	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to broadcast the windshield-wiper activation and/or ABS-engagement activation in near real-time to other ADS-equipped vehicles with at least Cooperation Class A capabilities within its long-range communications approximately every 1 s.
RWM-N1.07	Visual alerts about adverse-weather conditions from ITS devices or radio broadcasts.	RWM-R1.11	An ADS-equipped vehicle with onboard weather-detection equipment shall be able to broadcast at a minimum the following weather-related data (assuming the applicable sensor data are available): • Pavement-surface condition indication. • Precipitation-presence indication. • Icing-conditions indication. • Location indication. • Weather sensor operational status (failed/operational).

Operational Need Identifier	Operational Need	Functional Requirement Identifier	Functional Requirement
RWM-N1.07	Visual alerts about adverse-weather conditions from ITS devices or radio broadcasts.	RWM-R1.14	A TMS shall be able to broadcast at a minimum the following weather-related data (if the related sensor data are available): • Pavement-surface condition indication. • Precipitation-presence indication. • Icing-conditions indication. • Location indication. • Weather sensor operational status (failed/operational).
RWM-N1.08	Need information on acceptable speed limits to safely navigate roadways affected by adverse-weather conditions.	RWM-R1.17	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to interpret received intentions to reduce speeds due to weather events and process these intentions in conjunction with the locations, speeds, headings, and brake status received from other ADS-equipped vehicles with Cooperation Class A capabilities or higher.
RWM-N1.08	Information on acceptable speed limits to safely navigate roadways affected by adverse-weather conditions.	RWM-R1.18	An ADS-equipped vehicle shall be able to detect a reduction in speed of a vehicle not equipped with ADS if it is in detection range.
RWM-N1.08	Information on acceptable speed limits to safely navigate roadways affected by adverse-weather conditions.	RWM-R1.21	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use the adverse-weather data from a TMS to determine when and where it can safely and efficiently resume its previous travel speeds.
RWM-N1.08	Information on acceptable speed limits to safely navigate roadways affected by adverse-weather conditions.	RWM-R1.22	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use the adverse-weather data from an ADS-equipped vehicle with weather-detection equipment to determine when and where it can safely and efficiently resume its previous travel speeds.
RWM-N1.09	Capability to determine pavement temperature and presence of water, snow, or ice on the roadway.	RWM-R1.04	An ADS-equipped vehicle with onboard weather detection equipment shall be able to broadcast at a minimum the following weather-related data (if the related sensors are onboard and are functioning properly): • Wet-pavement indication. • Icy-pavement indication. • Black ice on pavement indication. • Weather sensor operational status (failed/operational).

Operational Need Identifier	Operational Need	Functional Requirement Identifier	Functional Requirement
RWM-N1.09	Capability to determine pavement temperature and presence of water, snow, or ice on the roadway.	RWM-R1.07	A TMS shall be able to broadcast at a minimum the following weather-related data (assuming the applicable sensors data are available): • Pavement-surface condition indication. • Precipitation-presence indication. • Icing-conditions indication. • Location indication. • Weather-sensor operational status (failed/operational).
RWM-N1.09	Capability to determine pavement temperature and presence of water, snow, or ice on the roadway.	RWM-R1.11	An ADS-equipped vehicle with onboard weather-detection equipment shall be able to broadcast at a minimum the following weather-related data (assuming the applicable sensor data are available): • Pavement-surface condition indication. • Precipitation-presence indication. • Icing-conditions indication. • Location indication. • Weather-sensor operational status (failed/operational).
RWM-N1.09	Capability to determine pavement temperature and presence of water, snow, or ice on the roadway.	RWM-R1.14	A TMS shall be able to broadcast at a minimum the following weather-related data (if the related sensor data are available): • Pavement-surface condition indication. • Precipitation-presence indication. • Icing-conditions indication. • Location indication. • Weather-sensor operational status (failed/operational).
RWM-N1.10	Provide road weather condition information to ADS-equipped vehicles in a geofenced area.	RWM-R1.20	A TMS shall be able to continuously broadcast the detected RWIS weather data, including any modifications to the geofenced adverse-weather area approximately every 10 s.
RWM-N1.11	Provide road weather condition response suggestions (reduced speed limits and recommended headways) to ADS-equipped vehicles in a geofenced area.	RWM-R1.21	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use the adverse-weather data from a TMS and use that information to determine when and where it can safely and efficiently resume its previous travel speeds.
RWM-N1.11	Provide road weather condition response suggestions (reduced speed limits and recommended headways) to ADS-equipped vehicles in a geofenced area.	RWM-R1.22	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use the adverse-weather data from an ADS-equipped vehicle with weather-detection equipment to determine when and where it can safely and efficiently resume its previous travel speeds.
RWM-N1.12	Gather and process data from ITS devices and ADS-equipped vehicles to monitor current traffic conditions.	RWM-R1.16	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to broadcast its driving path for the previous 1 min approximately every 1 s.

Operational Need Identifier	Operational Need	Functional Requirement Identifier	Functional Requirement
RWM-N1.12	Gather and process data from ITS devices and ADS-equipped vehicles to monitor current traffic conditions.	RWM-R1.23	A TMS shall be able to receive vehicle operations and weather-related data (e.g., locations, speeds, headings, brake status, and available weather data) from an ADS-equipped vehicle with at least Cooperation Class A capabilities in a specified area that can provide weather data. Communications shall be possible approximately every 1 s via short- or long-range communications infrastructure to the TMS.

CHAPTER 6. USE CASE: WZM

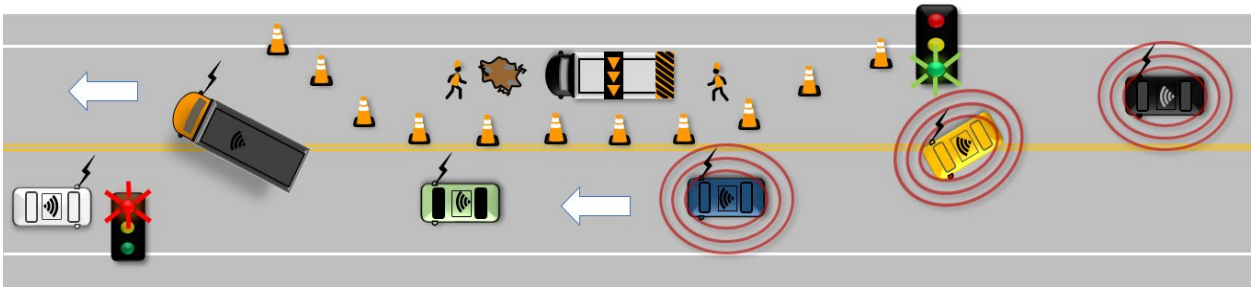
PRIORITY SITUATION 4 TREATMENT: ADS-EQUIPPED VEHICLES NAVIGATING A ONE-LANE, TWO-WAY TRAFFIC TAPER IN A WORK ZONE

The subject of this situational analysis is an ADS feature with a specified ODD that includes operation of ADS-equipped vehicles safely navigating a work zone on a roadway with one lane in each direction with one lane blocked because of a work zone. This will require the vehicle to temporarily merge into the lane going in the opposite direction to pass the work zone. The roadway is populated by vehicles of different Automation Levels and Cooperation Classes.

ADS-equipped vehicles travel through the ADS vehicle travel areas of advanced warning/notification, transition, activity, and termination. These travel areas are defined in chapter 2.

Situation 4 involves several vehicles positioned on a roadway with one lane in each direction. One lane is blocked because of a work zone and the presence of workers. The work-zone setup will follow MUTCD guidelines. Typically, the traffic control for similar situations can be performed by a flagger or a traffic light. In this situation, a traffic light with the ability to transmit signal phasing and timing (SPaT) data will be used, and the TMS provides digital layout of the work zone. ADS-equipped vehicles approaching the work zone will have to gradually slow down to the work-zone speed limit, detect the signal phase, cross over the double yellow centerline to merge into the lane going in the opposite direction if the signal is green (i.e., bottom indication is active), and change lanes again to go back to regular operations after passing the work zone. The vehicles traveling in the opposite direction will receive a red signal (i.e., top indication is active) and stop until the lane is cleared of oncoming traffic.

The situational layout is depicted in figure 24. The situation includes vehicles with different cooperation class capabilities shown in red circles in the graphic.



Source: FHWA.

Figure 24. Illustration. WZM situational layout.

Operational Needs

This situation is intended to address specific operational user needs, detailed in table 20 through table 23.

Table 20. Operational needs for WZM.

Operational Need Identifier	Operational Need
WZM-N1.01	Safely approach, navigate through, and clear a work zone.
WZM-N1.02	Possess situational awareness regarding the work zone, including workers and TCDs.
WZM-N1.03	Gather, integrate, process, and disseminate work-zone information.

Table 21. WZM—operational needs for ADS-equipped vehicles in a work zone.

Operational Need Identifier	Operational Needs for ADS-Equipped Vehicles
WZM-N1.04	Receive and process SPaT and work-zone geographic layout (MAP) messages from traffic signals controlling the approaches to the work zone.
WZM-N1.05	Gather location and speed information from vehicles near ADS-equipped vehicles.
WZM-N1.06	Detect any workers or TCDs encroaching on the travel lane.
WZM-N1.07	Detect vehicles incapable of cooperating with other vehicles.
WZM-N1.08	Detect vehicles entering or exiting the work zone.

Table 22. WZM—operational needs for non-ADS equipped vehicles (human driver).

Operational Need Identifier	Operational Need for Non-ADS (Human Driver)
WZM-N1.09	Visual alerts upstream and when navigating the work zone.

Table 23. WZM—operational needs for TMS.

Operational Need Identifier	Operational Need for Traffic Management Service
WZM-N1.10	Provide geofenced work-zone information, including speed limits, to ADS-equipped vehicles approaching the work zone.
WZM-N1.11	Manage variable message signs and other traveler information systems to provide vehicles approaching the work zone with visual and/or audible information about the work zone.
WZM-N1.12	Gather and process data from ITS devices and ADS-equipped vehicles to monitor current traffic conditions.

Stakeholders and Entities

Researchers can execute the operational situation using several vehicles. The focus of CARMA is on Automation Level 3 or higher and Cooperation Class B or higher, but under real-world conditions, other vehicles will also be encountered that might be equipped with lower Automation Levels and Cooperation Classes. The following stakeholders and entities, and their associated minimum vehicle configurations, should be considered when executing this operational situation within CARMA:

- Vehicle 1 navigating the controlled one-way work zone-related, one-lane, two-way traffic taper:
  - ADS vehicle with Automation Level 3 and Cooperation Class B.
- Vehicle 2 (in front of the first vehicle arriving at the work zone-related, one-lane, two-way traffic taper):
  - ADS vehicle with Automation Level 3 and Cooperation Class B.
- Vehicle 3 (behind the first vehicle arriving at the work zone-related, one-lane, two-way traffic taper):
  - ADS vehicle with Automation Level 3 and Cooperation Class B.

Traffic lights, flaggers, or broadcasting work-zone channeling devices (i.e., cones) at each end of the work zone can be used to manage the one-way traffic through the work zone.

Another stakeholder is a TMS operator (or software package) that will monitor the positions of each vehicle for recording and storage purposes. While many smaller, one-way traffic taper work zones are managed locally without control or monitoring by a TMS, a TMS could also control and manage a traffic signal or configure a broadcasting work-zone channeling device. If an RSU is used for the communications, then the TMS would need to monitor the communications associated with the RSU.

User-Oriented Operational Description

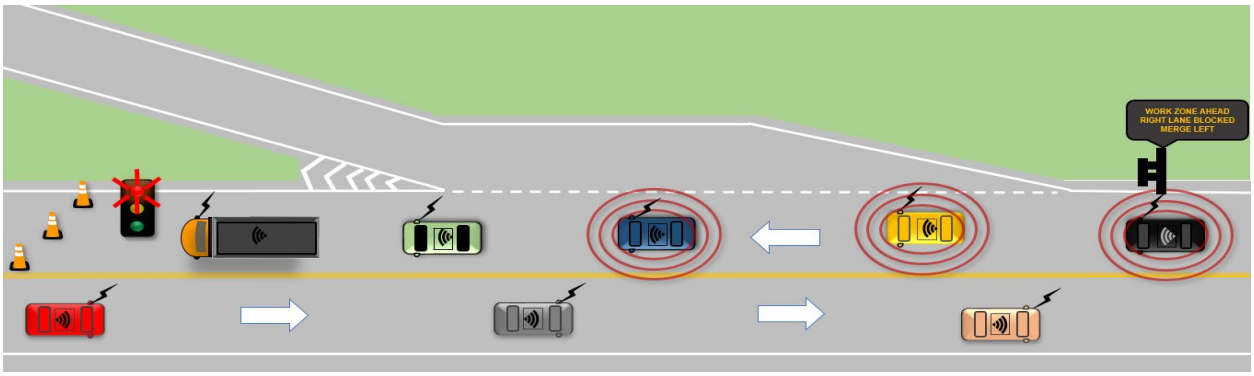
Concept Diagram

Priority Situation 4 includes several ADS vehicle travel areas—advanced warning/notification, transition, activity, and termination—that are explained in the following sections. The concepts include an overview diagram for each ADS-equipped vehicle travel area, a description, and a table that shows how vehicles with different Automation Levels and Cooperation Classes would react and respond within each travel area of the one-lane, two-way traffic taper WZM situation.

For the following descriptions of ADS vehicle travel areas to be used within CARMA, all vehicles support at least Cooperation Class B capabilities.

Advanced Warning/Notification Vehicle Travel Area

Within the advanced warning/notification vehicle travel area, ADS-equipped vehicles travel along a one-lane roadway when they all receive a TMS broadcast with a notification of a downstream work zone that closes the lane in which the vehicles are traveling and they will have to obey a traffic signal prior to the work zone. Alternatively, the vehicles could exit to take a detour, as shown in figure 25.



Source: FHWA.

Figure 25. Illustration. WZM-ADS-equipped vehicles receiving a notification.

The information from the TMS includes location of the work zone (start and end locations), start and end work times in the work zone, queue information prior to the work zone (if any), and alternative route suggestions (if any). The TMS also takes advantage of a VMS located just before the nearest exit and prior to the work zone by posting a message to warn vehicles of the work zone and the availability of a detour.

The first vehicles downstream of the vehicles under test (those with circles) have arrived and are stopped in front of a traffic light regulating the traffic around the work zone, which currently shows a red light (top indication is active). The upstream vehicles receive the traffic-signal status information as well as the work-zone layout via a map data (MAP) message. The upstream vehicles process the data to avoid any rear-end accidents and/or to minimize the deceleration and/or stop time at the signal.

The traffic light operates on a fixed-cycle basis and does not react to locally detected volumes or delays (this is the normal mode of operations, particularly in more rural areas and/or in conjunction with small, temporally limited work zones). The traffic light is assumed to be configured with a preprogrammed cycle length and green light splits that are managed locally (as opposed to being managed by a TMS with signal-control capabilities, which is an option often used in cities). However, the traffic light provides its light-status data (e.g., SPaT data, failure status) to the vehicles directly via short- or long-range communications. Furthermore, the TMS broadcasts the digital layout of the work zone (via MAP messages) to the vehicles, which includes work-zone start location (first channeling device) and date/time, channeling devices taper angle, work-zone end location (first channeling device where the taper ends) and taper-end angle, as well as other data, such as work-zone entry and exit locations (if applicable).

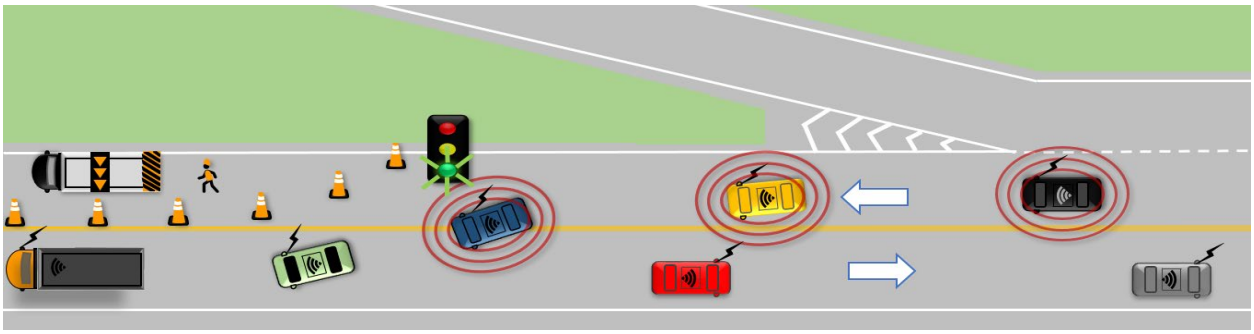
Alternatively, instead of traffic lights managing the traffic around such a work zone, human or mechanical flaggers can be positioned at each end of the work zone to coordinate which direction is open for traffic as well as to ensure that the traffic already in the work zone has cleared. Another alternative or addition is the provision of smart channeling devices (e.g., intelligent cones with broadcasting capabilities), which could broadcast their locations as well as other information.

Simultaneously, all vehicles involved in this situation are communicating with each other, exchanging data about their operational status (e.g., location, speed, and heading). Those

vehicles that follow the suggested detour would broadcast that fact via their location, speed, heading, and potential intention data; however, for this situation, no vehicle is assumed to follow a detour suggestion.

Vehicle Travel Transition Area

Within the transition area, ADS-equipped vehicles are restarting or accelerating to the posted work-zone speed limit, which is lower than the normal speed limit and appropriate for the work zone, to pass the work zone after the traffic light has changed to green (bottom indication is active) as shown in figure 26. The traffic light is programmed to allow sufficient time for vehicles in the opposite direction to clear the work zone and not block the one lane available within the work zone for oncoming vehicles. The traffic light continues to broadcast its light status, including the change to green (bottom indication is active) for the direction from which the vehicles under test are coming.



Source: FHWA.

Figure 26. Illustration. WZM—vehicle transition area.

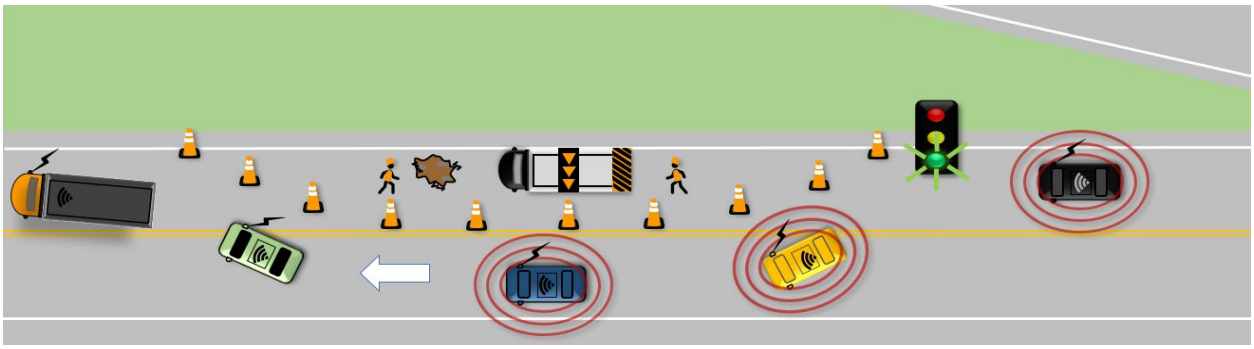
The ADS-equipped vehicles, which are programmed not to cross a double yellow centerline, are crossing the double yellow centerline to pass the work zone in the one available lane. This maneuver will only take place when the light is green (bottom indication is active) and the downstream vehicles have moved. The ADS-equipped vehicles broadcast their locations, speeds, headings, and path intentions. ADS-equipped vehicles with Cooperation Class C capabilities exchange data with each other to coordinate the moving maneuvers each vehicle is executing.

ADS-equipped vehicles arriving late in the green cycle (bottom indication is active) at the traffic light receive, process, analyze, and use SPaT and MAP data, as well as the location data from other downstream vehicles, to determine whether they can pass the traffic light while still green (bottom indication is active) or if they have to prepare to stop in front of the traffic light.

Vehicle Travel Activity Area

Within the activity area, ADS-equipped vehicles on the one-directional lane pass the work zone. They broadcast their current locations, as well as their intended-path information, to each other and any other listening device (e.g., TMS via short- or long-range communications media). Any unusual obstacles (e.g., a vehicle exiting from the actual protected work zone or a person working within the work zone) will be detected by the nearest upstream vehicle and reported to all other nearby vehicles and the TMS.

The traffic light in the direction of the ADS-equipped vehicles is still continuously broadcasting its status, including remaining green time (bottom indication is active) within a geofenced area around the work zone, which is received by ADS-equipped vehicles, as shown in figure 27.

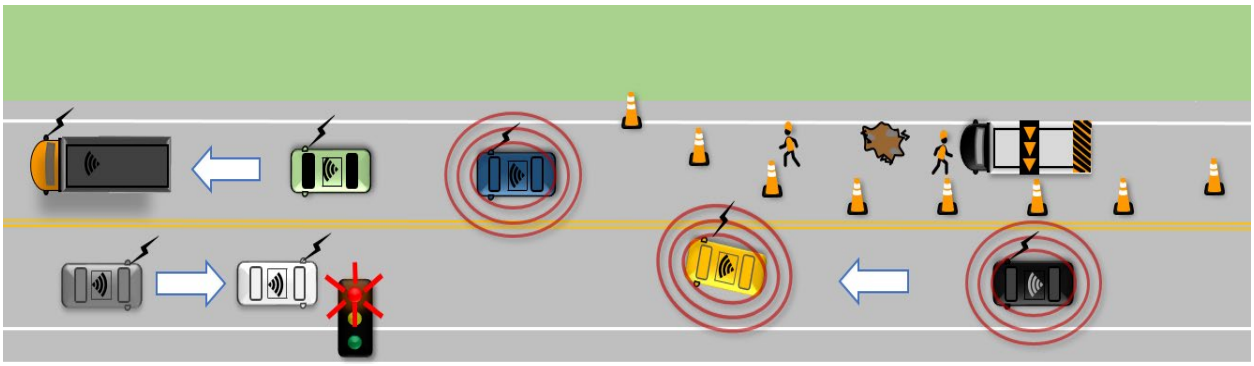


Source: FHWA.

Figure 27. Illustration. WZM—vehicle activity area.

Vehicle Travel Termination Area

Within the termination area, ADS-equipped vehicles have reached the end of the contraflow one-lane work-zone area and are moving over into their original through lane, as shown in figure 28.



Source: FHWA.

Figure 28. Illustration. WZM—termination area.

ADS-equipped vehicles with Cooperation Class C capabilities are exchanging data to negotiate the merging area between the work-zone end and the vehicles in the opposite direction waiting at their traffic light, which still shows a red light (top indication is active).

Once the ADS-equipped vehicles have reached the through lane in their direction and passed the reduced speed limit area, they accelerate to the normal speed limit, while broadcasting their location, speed, and heading information to other vehicles in the vicinity.

As soon as the work zone is resolved, the TMS removes the work-zone warning and alternate-route message from the upstream VMS.

Trigger to Invoke Situation of ADS-Equipped Vehicles Navigating a One-Lane, Two-Way Traffic Taper in a Work Zone

Priority situation 4 is triggered when ADS-equipped vehicles are first informed of the existence of the work zone upstream either by the TMS or a local method, which is broadcasting data of the downstream work zone. Additionally, vehicles are informed via an upstream VMS where the TMS posted the warning message. The following indicators are designated as triggers to invoke responses of ADS-equipped vehicles:

- Broadcast from the TMS.
- Broadcast from a local device as part of the work-zone setup.
- Reading/comprehending a corresponding message posted on a VMS (optical character recognition technology).

Additional triggers are needed and will be used when ADS-equipped vehicles approach the work zone in response to the traffic light (or flagger or broadcasting channeling device) and to cross the otherwise noncrossable double yellow line.

Requirements

The requirements to address the situation and to fulfill the stated user-operational needs are defined in table 24.

Table 24. Requirements for ADS-equipped vehicles navigating a one-lane, two-way traffic taper in a work zone.

Functional Requirement Identifier	Functional Requirement	Applicable to CARMA
BT-R1.01	See table 6 for the same requirement FR ID number.	Yes, Cooperation Class B and higher
BT-R1.02	See table 6 for the same requirement FR ID number.	Yes, Cooperation Class B and higher
BT-R1.03	See table 6 for the same requirement FR ID number.	Yes, Cooperation Class B and higher
BT-R1.04	See table 6 for the same requirement FR ID number.	Yes, Cooperation Class B and higher
WZM-R1.01	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use work-zone data (start and end location, lanes affected, date/time of work-zone activities, associated speed limits prior to and within the work zone) obtained from the TMS via short-range communications approximately every 1 s.	Yes, Cooperation Class B and higher

Functional Requirement Identifier	Functional Requirement	Applicable to CARMA
WZM-R1.02	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use data about the work-zone geographic layout obtained from the TMS via short-range communications approximately every 1 s.	Yes, Cooperation Class B and higher
WZM-R1.03	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use traffic-signal status data from the traffic light via short-range communications approximately every ⅒ s.	Yes, Cooperation Class B and higher
BT-R1.05	See table 6 for the same requirement FR ID number.	Optional, Cooperation Class B and higher
BT-R1.06	See table 6 for the same requirement FR ID number.	Optional, Cooperation Class B and higher
WZM-R1.04	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to receive, decode, process, analyze, and use work-zone data (start and end location, lanes affected, date/time of work-zone activities, associated speed limits prior to and within the work zone) obtained from the TMS via long-range communications approximately every 1 s.	Optional
WZM-R1.05	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to receive, decode, process, analyze, and use data about the work-zone geographic layout obtained from the TMS via long-range communications approximately every 1 s.	Optional
WZM-R1.06	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to receive, decode, process, analyze, and use traffic-signal status data from the traffic light via long-range communications approximately every ⅒ s.	Optional
WZM-R1.07	An ADS-equipped vehicle shall be able to detect, decode, process, analyze, and react to the work-zone message posted on a VMS prior to the work zone using visual detection onboard sensors and optical code recognition technology.	No
WZM-R1.08	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to broadcast its driving path for the previous 1 min approximately every 1 s.	No
WZM-R1.09	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to broadcast its intended future driving path for at least the next 15 s approximately every 3 s.	Yes, Cooperation Class B and higher
WZM-R1.10	An ADS-equipped vehicle shall be able to interpret the presence of a tapered barrier (in the form of channeling devices) in conjunction with a traffic light showing green to allow it to cross a double yellow line and proceed in the opposing driving lane to pass the work-zone area (before moving into the opposite direction lane).	Yes
WZM-R1.11	An ADS-equipped vehicle shall be able to detect any oncoming vehicles still present in the opposing lane before moving into the opposite direction lane.	Yes
WZM-R1.12	An ADS-equipped vehicle shall not drive into the opposing lane if any oncoming vehicles have been detected (and instead stop in its own lane until all oncoming vehicles have passed).	Yes
WZM-R1.13	An ADS-equipped vehicle shall be able to detect and either slow down or stop when a work-zone vehicle exits the work zone.	Yes

Functional Requirement Identifier	Functional Requirement	Applicable to CARMA
WZM-R1.14	An ADS-equipped vehicle shall be able to detect and either slow down or stop when a worker in the work zone steps into the lane in front of the ADS-equipped vehicle.	Optional
WZM-R1.15	An ADS-equipped vehicle with Cooperation Class C capabilities shall be able to send and receive, decode, process, analyze, and use detailed intention data, including ACKs and NAKs when cooperating with other ADS-equipped vehicles with Cooperation Class C capabilities during the work-zone bypass maneuver, including interactions with work-zone vehicles coming out of or driving into the work zone.	Yes
WZM-R1.16	An ADS-equipped vehicle shall be able to use onboard sensors to detect the location, speed, and heading at suitable sensing intervals of non-ADS-equipped vehicles with no cooperation capabilities within its vicinity.	Yes
BT-R1.16	See table 6 for the same requirement FR ID number.	Optional
WZM-R1.17	An ADS-equipped vehicle shall be able to detect, decode, process, analyze, and use the end-of-work-zone area and merge into the original lane in a safe and efficient manner.	Yes
WZM-R1.18	An ADS-equipped vehicle shall use the end-of-work-zone area information to determine how it can safely and efficiently resume its previous travel speed.	Yes
BT-R1.17	See table 6 for the same requirement FR ID number.	Yes
WZM-R1.19	A TMS shall be able to broadcast a work-zone notification message to a geofenced area around the work zone. Communications shall be possible approximately every 1 s via short- or long-range communications infrastructure to the TMS.	Yes
WZM-R1.20	A TMS shall be able to broadcast the geographic layout of the work zone to a geofenced area around the work zone. Communications shall be possible approximately every 1 s via short- or long-range communications infrastructure to the TMS.	Yes
WZM-R1.21	A TMS shall be able to post a message on VMS prior to the work zone.	Yes
WZM-R1.22	A TMS shall be able to modify a message posted on VMS prior to the work zone.	Yes
WZM-R1.23	A TMS shall be able to delete a message posted on VMS prior to the work zone and display the previously displayed message (if applicable).	Yes
WZM-R1.24	A traffic-light system installed prior to the work zone shall be able to broadcast its traffic-light status, including the green-light status approximately every ⅒ s via short-range communications.	Yes
WZM-R1.25	A traffic-light system installed prior to the work zone shall be able to broadcast its traffic-light status, including the green-light status approximately every ⅒ s via long-range communications.	Optional

ACK = acknowledgment; FR ID = functional requirement identification.

Performance Metrics

Key performance metrics for monitoring and evaluating operations during execution of this situation, some of which were adapted from *A Framework for Automated Driving System Testable Cases and Scenarios*, should include the following:

- Separation distances—longitudinal distances between the vehicles in the test. Separation distances are used to determine safe distances and the frequency of infringement of those distances (Thorn et al. 2018).

- Disengagements—occurrence frequency when safety drivers deactivate the ADS feature being tested and take manual control of the vehicles (Thorn et al. 2018).
- Travel speeds driven—speeds driven by each of the vehicles during the tests will be used to create an accurate picture (playback) for evaluating driving within the vehicle travel areas.
- Deceleration rate—vehicle's change-of-speed rate when approaching the work zone (Thorn et al. 2018).
- SPaT message latency—the time difference between origination of the SPaT message from the controller to receipt by the vehicle, including time to decompose and read the message.
- MAP message latency—the time difference between origination of the MAP message from the TMS to receipt by the vehicle, including time to decompose and read the message.
- Data exchanges during negotiation (Cooperation Class C)—capture all data exchanges between two Cooperation Class C ADS-equipped vehicles, vehicle 1 and vehicle 2, to determine whether the maneuver negotiations occurred as designed. The data exchanges include the following data types:
    - Total duration of negotiation process.
    - Frequency of negotiation success/failure (NAKs from neighboring vehicles).
    - Number of attempts before a plan is accepted by all affected neighbors.
    - Message latency.

Message latency refers to the time difference between message origination on vehicle 1 to reading of message by vehicle 2. The latency time includes the time to compose the message, sending the message from vehicle 1's guidance computer to vehicle 1's OBU, queuing time on vehicle 1's OBU, radio transmission from vehicle 1 to vehicle 2, message constitution and queueing on vehicle 2's OBU, sending the message from vehicle 2's OBU to vehicle 2's guidance computer, and the time for vehicle 2 to decompose and read the message.

Requirements Traceability Matrix for WZM Operational Needs and Functional Requirements

Table 25 traces the relationship between operational needs and functional requirements.

Table 25. Requirements traceability matrix for ADS-equipped vehicles navigating a one-lane, two-way traffic taper in a work zone.

Operational Need Identifier	Operational Need	Functional Requirement Identifier	Functional Requirement
WZM-N1.01	Safely approach, navigate through, and clear a work zone.	BT-R1.01	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall provide for the ability to avoid crashes with other vehicles (vehicles with or without cooperation class capabilities) prior to, during, and after completion of the merging maneuver. Communications shall be possible approximately every ⅒ s.
WZM-N1.02	Situational awareness regarding the work area including the workers and TCD.	BT-R1.02	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to broadcast its location, speed, heading, and brake status approximately every ⅒ s.
WZM-N1.02	Situational awareness regarding the work area including the workers and TCD.	BT-R1.03	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use locations, speeds, and headings from other ADS-equipped vehicles with at least Cooperation Class A capabilities within its short-range communications approximately every ⅒ s.
WZM-N1.02	Situational awareness regarding the work area including the workers and TCD.	BT-R1.04	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use braking status from other ADS-equipped vehicles with at least Cooperation Class A capabilities within its short-range communications approximately every ⅒ s.
WZM-N1.03	Gather, integrate, process, and disseminate work-zone information.	WZM-R1.01	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use work-zone data (start and end location, lanes affected, date/time of work-zone activities, associated speed limits prior to and within the work zone) obtained from the TMS via short-range communications approximately every 1 s.
WZM-N1.03	Gather, integrate, process, and disseminate work-zone information.	WZM-R1.02	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use data about the work-zone geographic layout obtained from the TMS via short-range communications approximately every 1 s.
WZM-N1.03	Gather, integrate, process, and disseminate work-zone information.	WZM-R1.04	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to receive, decode, process, analyze, and use work-zone data (start and end location, lanes affected, date/time of work-zone activities, associated speed limits prior to and within the work zone) obtained from the TMS via long-range communications approximately every 1 s.

Operational Need Identifier	Operational Need	Functional Requirement Identifier	Functional Requirement
WZM-N1.03	Gather, integrate, process, and disseminate work-zone information.	WZM-R1.05	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to receive, decode, process, analyze, and use data about the work-zone geographic layout obtained from the TMS via long-range communications approximately every 1 s.
WZM-N1.03	Gather, integrate, process, and disseminate work-zone information.	WZM-R1.10	An ADS-equipped vehicle shall be able to interpret the presence of a tapered barrier (i.e., channeling devices) in conjunction with a traffic light showing green to allow it to cross a double yellow line and proceed in the opposing driving lane to pass the work-zone area (before moving into the opposite direction lane).
WZM-N1.03	Gather, integrate, process, and disseminate work-zone information.	WZM-R1.07	An ADS-equipped vehicle shall be able to detect, decode, process, analyze, and react to the message related to the work zone posted on a VMS prior to the work zone using visual detection onboard sensors and optical code recognition technology.
WZM-N1.03	Gather, integrate, process, and disseminate work-zone information.	WZM-R1.10	An ADS-equipped vehicle shall be able to interpret the presence of a tapered barrier (i.e., channeling devices) in conjunction with a traffic light showing green to allow it to cross a double yellow line and proceed in the opposing driving lane to pass the work-zone area (before moving into the opposite direction lane).
WZM-N1.04	Receive and process traffic SPaT and work-zone geographic layout (MAP) messages from traffic signals controlling the approaches to the work zone.	WZM-R1.03	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use traffic-signal status data from the traffic light via short-range communications approximately every ⅒ s.
WZM-N1.04	Receive and process traffic SPaT and work-zone geographic layout (MAP) messages from traffic signals controlling the approaches to the work zone.	WZM-R1.06	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to receive, decode, process, analyze, and use traffic-signal status data from the traffic light via long-range communications approximately every ⅒ s.
WZM-N1.05	Location and speed information from vehicles near ADS-equipped vehicles.	BT-R1.05	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use locations, speeds, and headings from other ADS-equipped vehicles with at least Cooperation Class A capabilities via long-range communications within a configurable geofenced area approximately every ⅒ s.
WZM-N1.05	Location and speed information from vehicles near ADS-equipped vehicles.	BT-R1.06	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to receive, decode, process, analyze, and use braking status from other ADS-equipped vehicles with at least Cooperation Class A capabilities via long-range communications within a configurable geofenced area approximately every ⅒ s.

Operational Need Identifier	Operational Need	Functional Requirement Identifier	Functional Requirement
WZM-N1.05	Location and speed information from vehicles near ADS-equipped vehicles.	WZM-R1.08	An ADS-equipped vehicle with at least Cooperation Class A capabilities shall be able to broadcast its driving path for the previous 1 min approximately every 1 s.
WZM-N1.05	Location and speed information from vehicles near ADS-equipped vehicles.	WZM-R1.09	An ADS-equipped vehicle with at least Cooperation Class B capabilities shall be able to broadcast its intended future driving path for at least the next 15 s approximately every 3 s.
WZM-N1.06	Detect any workers or TCDs encroaching on the travel lane.	WZM-R1.14	An ADS-equipped vehicle shall be able to detect and either slow down or stop when a worker within the work zone steps into the lane in front of the ADS-equipped vehicle.
WZM-N1.07	Detect vehicles incapable of cooperating with other vehicles.	WZM-R1.16	An ADS-equipped vehicle shall be able to use onboard sensors to detect the location, speed, and heading at suitable sensing intervals of vehicles not equipped with ADS with no cooperative automation capabilities.
WZM-N1.08	Detect vehicles entering or exiting the work zone.	WZM-R1.11	An ADS-equipped vehicle shall be able to detect any oncoming vehicles still present in one lane before moving into the opposite direction lane.
WZM-N1.08	Detect vehicles entering or exiting the work zone.	WZM-R1.12	An ADS-equipped vehicle shall not drive into the opposing lane if any oncoming vehicles have been detected (and instead stop in its own lane until all oncoming vehicles have passed).
WZM-N1.08	Ability to detect vehicles entering or exiting the work zone.	WZM-R1.13	An ADS-equipped vehicle shall be able to detect and either slow down or stop when a work-zone vehicle exits the work zone.
WZM-N1.09	Visual alerts upstream and when navigating the work zone.	WZM-R1.11	An ADS-equipped vehicle shall be able to detect any oncoming vehicles still present in the lane before moving into the opposite direction lane.
WZM-N1.09	Visual alerts upstream and when navigating the work zone.	WZM-R1.12	An ADS-equipped vehicle shall not drive into the opposing lane if any oncoming vehicles have been detected (and instead stop in its own lane until all oncoming vehicles have passed).
WZM-N1.09	Visual alerts upstream and when navigating the work zone.	WZM-R1.13	An ADS-equipped vehicle shall be able to detect and either slow down or stop when a work-zone vehicle exits the work zone.
WZM-N1.09	Visual alerts upstream and when navigating the work zone.	WZM-R1.14	An ADS-equipped vehicle shall be able to detect and either slow down or stop when a worker within the work zone steps into the lane in front of the ADS-equipped vehicle.
WZM-N1.09	Visual alerts upstream and when navigating the work zone.	WZM-R1.15	An ADS-equipped vehicle with Cooperation Class C capabilities shall be able to send, receive, decode, process, analyze, and use detailed intention data including ACKs and NAKs when cooperating with other ADS-equipped vehicles with Cooperation Class C capabilities during the work-zone bypass maneuver including interactions with work-zone vehicles coming out of or driving into the actual work zone.

Operational Need Identifier	Operational Need	Functional Requirement Identifier	Functional Requirement
WZM-N1.09	Visual alerts upstream and when navigating the work zone.	WZM-R1.16	An ADS-equipped vehicle shall be able to use onboard sensors to detect the location, speed, and heading at suitable sensing intervals of non-ADS-equipped vehicles with no cooperative automation capabilities.
WZM-N1.09	Visual alerts upstream and when navigating the work zone.	BT-R1.16	An ADS-equipped vehicle shall have a means to visually display to the driver the location of other vehicles about which it has information.
WZM-N1.09	Visual alerts upstream and when navigating the work zone.	WZM-R1.17	An ADS-equipped vehicle shall be able to detect, decode, process, analyze, and use the end of the work-zone area and merge into the original lane in a safe and efficient manner.
WZM-N1.09	Visual alerts upstream and when navigating the work zone.	WZM-R1.18	An ADS-equipped vehicle shall use the end of the work-zone area information to determine how it can safely and efficiently resume its previous travel speed.
WZM-N1.10	Geofenced work-zone information, including speed limits to ADS-equipped vehicles approaching the work zone.	WZM-R1.19	A TMS shall be able to broadcast a work-zone notification message to a geofenced area around the work zone. Communications shall be possible approximately every 1 s via short- or long-range communications to the TMS.
WZM-N1.10	Geofenced work-zone information, including speed limits to ADS-equipped vehicles approaching the work zone.	WZM-R1.20	A TMS shall be able to broadcast the geographic layout of the work zone to a geofenced area around the work zone. Communications shall be possible approximately every 1 s via short- or long-range communications to the TMS.
WZM-N1.11	Ability to manage variable message signs and other traveler information systems to provide vehicles approaching the work zone with visual and/or audible information about the work zone.	WZM-R1.21	A TMS shall be able to post a message on VMS prior to the work zone.
WZM-N1.11	Ability to manage variable message signs and other traveler information systems to provide vehicles approaching the work zone with visual and/or audible information about the work zone.	WZM-R1.22	A TMS shall be able to modify a message posted on VMS prior to the work zone.
WZM-N1.11	Ability to manage VMSs and other traveler information systems to provide vehicles approaching the work area with visual and/or audible information about the work zone.	WZM-R1.23	A TMS shall be able to delete a message posted on VMS prior to the work zone and display the previously displayed message, if applicable.

Operational Need Identifier	Operational Need	Functional Requirement Identifier	Functional Requirement
WZM-N1.12	Gather and process data from ITS devices and ADS-equipped vehicles to monitor current traffic conditions.	BT-R1.17	A TMS shall be able to receive aggregated data (e.g., locations, speeds, headings, and brake status) from each ADS-equipped vehicle with at least Cooperation Class A capabilities in a specified area. Communications shall be possible approximately every 1 s via short- or long-range communications to the TMS.

ACK = acknowledgment.

APPENDIX. KEY TSMO STRATEGIES AND THEIR RELATIONSHIP TO COOPERATIVE ADS

The TSMO strategies presented in table 26 through table 43 are profiled in tabular format in relation to CDA, strategy group, strategy, description, and Cooperation Classes applicable to the strategy.

Table 26 presents TSMO strategies for arterial management that provides users with a safe, efficient, and reliable trip.

Table 26. TSMO strategies for arterial management.

ID	TSMO Strategies	Description	Cooperation Class	Additional Benefit to Existing TSMO Strategy
1-1	**Access Management** Related strategies: Weather-Related Road Restrictions (8-6), Curbside Management (17-6)	Access management is the proactive management of vehicular access points to land parcels adjacent to all types of roadways. Techniques to control access include, for example, driveway spacing, safe turning lanes, and median treatments.	A, B	Improved real-time access allocation.
1-2	**Adaptive Signal Timing** Related strategies: Transit-Signal Priority (1-5), Truck Traffic Signal Priority (1-6), Weather-Responsive Traffic Signal Control (8-7)	Adaptive traffic signal control is a concept for which vehicular traffic in a network is detected at an upstream and/or downstream point and an algorithm is used to predict when the traffic will arrive and where the traffic will be located.	A, B	Improved real-time traffic detection. Reduced reliance on physical sensor devices and maintenance. Improved algorithms to adjust signal timing and queue management.
1-3	**Signal Retiming/Optimization** Related strategies: Signal Timing for Bicycles and Pedestrians (1-4)	Signal retiming/optimization strategy is a concept to optimize traffic flow.	A, B	Improved historical traffic data for nonreal-time adjustments. Reduced reliance on physical sensor devices and maintenance.
1-4	**Signal Timing for Bicycles and Pedestrians** Related strategies: Signal Retiming/Optimization (1-3)	Signal timing for bicycles and pedestrians is an operational strategy for reducing the delay pedestrians and bicyclists experience at traffic signals.	A, B	Ability to monitor the number of vehicles versus bicycles and pedestrians. Reduced reliance on physical sensor devices and maintenance.

ID	TSMO Strategies	Description	Cooperation Class	Additional Benefit to Existing TSMO Strategy
1-5	**TSP** Related strategies: Adaptive Signal Timing (1-2)	TSP is an operational strategy for reducing the delay transit vehicles experience at traffic signals.	A, B, C	Improved transit-vehicle detection. Enhanced real-time traffic-detection algorithms for priority.
1-6	**Truck Traffic Signal Priority** Related strategies: Adaptive Signal Timing (1-2)	Truck traffic signal priority is an operational strategy for reducing the delay commercial vehicle operators experience at traffic signals.	A, B, C	Improved freight-vehicle detection. Enhanced real-time traffic-detection algorithms for priority.

TSP = transit-signal priority.

Table 27 presents TSMO strategies for active traffic management (ATM), allowing TSMO operators the ability to dynamically manage recurring and nonrecurring congestion based on prevailing and predicted traffic conditions. Focusing on trip reliability, ATM maximizes the effectiveness and efficiency of the facility.

Table 27. TSMO strategies for ATM.

ID	TSMO Strategies	Description	Cooperation Class	Additional Benefit to Existing TSMO Strategy
2-1	**Dynamic Junction Control**	Dynamic junction control consists of dynamically allocating lane access on mainline and ramp lanes in interchange areas in which high traffic volumes are present and the relative demand on the mainline and ramps change throughout the day.	A, B	More accurate junction control. High accuracy of traffic data and demand on mainline and ramps.
2-2	**Dynamic Merge Control**	Dynamic merge control consists of dynamically managing the entry of vehicles into merge areas with a series of advisory messages approaching the merge point that prepare motorists for an upcoming merge and encourage or direct consistent merging behavior.	A, B, C	Precise merge operations. Improved merge consistency.
2-3	**Lane Use Control** Related strategies: Traffic-Incident Management (11-2), Work-Zone Management (15-1)	Lane-use control signals are special overhead signals that permit or prohibit the use of specific lanes of a street or highway or that indicate the impending temporary closure of the lanes.	A, B	Improved use of lane-use control based on high-frequency traffic data. Improved safety for Cooperation Class B vehicles.
2-4	**Queue Warning** Related strategies: Motorist Advisory and Warning Systems (8-2), Break Long Queues on Arterials (17-3)	Queue warning systems advise motorists of approaching congested work zones, predictable bottlenecks, or areas with sight-distance limitations of traffic stoppage or slowdown.	A, B	Improved queue detection and location accuracy. Enhanced safety, particularly for Cooperation Class B vehicles.
2-5	**Reversible Lanes**	The reversible lanes operational strategy allows for the direction of the roadway to be reversed depending on traffic demand.	A, B, C	Improved reversal times based on additional traffic data. Improved conflict detection. Improved warning systems.

ID	TSMO Strategies	Description	Cooperation Class	Additional Benefit to Existing TSMO Strategy
2-6	**Ramp Metering**	Ramp meters are traffic signals installed on freeway onramps to control the frequency at which vehicles enter the flow of traffic on the freeway. Ramp metering reduces overall freeway congestion by managing the volume of traffic entering the freeway and by breaking up platoons that make it difficult to merge onto the freeway.	A, B, C	Improved mainline detection. Improved queue detection. Enhanced safety, particularly for Cooperation Class B vehicles.
2-7	**Real-Time Traffic Monitoring** Related strategies: Multimodal Regional Traveler Information (12-1), Real-Time Transit Arrival Information (12-4)	Real-time traffic monitoring is a strategy whereby traffic is monitored in real time through sensors, field devices, and third-party data to assist in ATM.	A, B	More comprehensive coverage for monitoring the roadway network and multiple modes.
2-8	**Speed Harmonization** Related strategies: Weather Speed Advisories (8-10), Lateral Vehicle Formations (17-14), Weather-Responsive VSL Application (8-10)	Speed harmonization (i.e., VSLs) is a strategy for managing traffic flow and congestion whereby the speed is adjusted based on traffic and weather conditions.	A, B	Improved speed harmonization due to high-frequency data. Enhanced safety, particularly for Cooperation Class B vehicles.
2-9	**Shoulder Lanes** Related strategies: Traffic-Incident Management (11-2), Work-Zone Management (15-1), Special Event Management (10-1)	This strategy enables the use of the shoulder as a travel lane, known as Hard Shoulder Running or temporary shoulder use, the strategy is typically applied according to congestion levels during peak periods and in response to incidents or other conditions as warranted during nonpeak periods.	A, B	Improved location-based detection of congestion levels. High-frequency data used to adjust when to implement hard-shoulder running. Enhanced safety.

Table 28 presents TSMO strategies for congestion pricing, which encompasses roadway pricing that varies by the time of the day and the level of congestion on the facility.

Table 28. TSMO strategies for congestion pricing.

ID	TSMO Strategies	Description	Cooperation Class	Additional Benefit to Existing TSMO Strategy
3-1	**Areawide Charging** Related strategies: Cordon Charging (3-2), Electronic Toll Collection (3-3), Variable Tolls (3-4)	This strategy involves per-unit charges within a given geographical area. Charges are typically based on miles traveled or zones crossed.	A, B	Personalized tolling. Tolls based on vehicle attributes and number of occupants.
3-2	**Cordon Charging** Related strategies: Areawide Charging (3-1), Electronic Toll Collection (3-3), Variable Tolls (3-4)	This strategy charges motorists for driving in congested core locations.	A, B	Personalized tolling. Tolls based on vehicle attributes and number of occupants.
3-3	**Electronic Toll Collection** Related strategies: Areawide Charging (3-1), Cordon Charging (3-2), High-Occupancy Toll Lanes (7-1)	This strategy uses electronic methods for collecting tolls to avoid delays associated with cash-based tolls.	A, B	Potential to reduce tolling infrastructure.
3-4	**Variable Tolls** Related strategies: Areawide Charging (3-1), Cordon Charging (3-2), Electronic Toll Collection (3-3), High-Occupancy Toll Lanes (7-1)	This strategy changes the toll fee, in real time, based on the level of traffic demand on the lanes.	A, B	Improved high-frequency data for use in adjusting price based on demand. More granular toll rates. Variable tolls based on vehicle attributes.

Table 29 presents TSMO strategies for emergency transportation operations, which provides users with a safe and efficient transportation system during emergency situations.

Table 29. TSMO strategies for emergency transportation operations.

ID	TSMO Strategies	Description	Cooperation Class	Additional Benefit to Existing TSMO Strategy
4-1	**Evacuation Management** Related strategies: Agency Coordination and Integration (18-9), Decision Support System (6-1), Freeway/Arterial Integrated Corridor Management (6-2), Mass Media Communication (18-4), Emergency Preparedness (4-2)	Evacuation management involves a predefined set of procedures to assist in a safe and efficient evacuation.	A, B, C	Improved evacuation strategy based on vehicle data. Improved safety particularly for Cooperation Class B vehicles.
4-2	**Emergency Preparedness** Related strategies: Evacuation Management (4-1), Emergency Response (4-3), Decision Support System (6-1)	This strategy relates to the activities, programs, and systems developed prior to an incident, disaster, or emergency, which are used to support and enhance prevention, response, and recovery. Preparedness efforts depend on the resources and risks of a jurisdiction or region.	A	Improved emergency preparedness through use of status data.
4-3	**Emergency Response** Related strategies: Traffic-Incident Management (11-2), Decision Support System (6-1), Computer-Aided Dispatch Integration with Traffic Management Center Operations (18-1), Evacuation Management (4-1), Emergency Preparedness (4-2), Incident Scene Pre-arrival Staging Guidance for Emergency Responders (RESP-STG) (16-4), Emergency Path Clearance (17-11), Safety Buffer (17-18), Lane Clear (17-13)	This strategy involves the Traffic Management Centers operational response to emergency incidents and disasters.	A, B, C	Improved safety from additional traffic data. Improved safety particularly for Cooperation Class B vehicles. Optimized emergency routing.

Table 30 presents TSMO strategies for freight technology and operations, which focus on the effective management of the system for freight transportation. The goal of freight transportation is to move goods safely, efficiently, and reliably throughout the region. This goal may range from satisfying customers (e.g., freight shippers, receivers, and carriers) to actual travel time on the system.

Table 30. TSMO strategies for freight technology and operations.

ID	TSMO Strategies	Description	Cooperation Class	Additional Benefit to Existing TSMO Strategy
5-1	**Fleet Management** Related strategies: Full-Function Service Patrols (11-1), Route Optimization for Snowplows (8-4), Automated Maintenance and Fleet-Management Systems (17-1)	This strategy involves location tracking and route planning for commercial and DOT-owned vehicles.	A, B	Improved fleet management from location data. Optimized route planning from additional traffic data.
5-2	**Commercial Motor Vehicle Electronic Screening/Clearance** Related strategies: Weather-Related Vehicle Restrictions (8-8), Digital Infrastructure Messaging (17-8), Lanes Dedicated as Transit or Trucks Only (7-3), Weather-Related Road Restrictions (8-6)	This strategy uses electronic screening/clearance of freight vehicles, including size and weight restrictions.	A, B	Automatic electronic screening and clearance of vehicle attributes. Ability to reduce travel time. Ability to charge fees based on O-D and vehicle attributes.

DOT = department of transportation; O-D = origin–destination.

Table 31 presents TSMO strategies for integrated corridor management, an approach that focuses on collaborative management of the transportation corridor as a system rather than the more traditional approach of managing individual assets on the corridor. Partners manage the corridor as an integrated asset to improve travel-time reliability and predictability, help manage congestion, and empower travelers through better information and more choices.

Table 31. TSMO strategies for integrated corridor management.

ID	TSMO Strategies	Description	Cooperation Class	Additional Benefit to Existing TSMO Strategy
6-1	**Decision Support System** Related strategies: Automated Maintenance Decision Support System (17-2), Evacuation Management (4-1), Emergency Preparedness (4-2), Emergency Response (4-3), Traffic-Incident Management (11-2), Freeway/Arterial Integrated Corridor Management (6-2)	Decision support system employs a decision algorithm for incident response that typically includes expert rules, prediction, and evaluation based on numerous data inputs.	A, B, C	Improved traffic flow from additional high-frequency data. Improved safety through optimized decision-support algorithms from additional data.
6-2	**Freeway/Arterial ICM** Related strategies: all	Freeway/arterial ICM involves the combined application of technologies and integration of various TSMO strategies and network partners, all working together to optimize traffic flow in a corridor.	A, B, C	Improved alternate routes. Creates benefits to load balancing. Improved safety through additional data inputs.

Table 32 presents TSMO strategies for managed lanes, which are highway facilities or a set of lanes in which operational strategies are proactively implemented and managed in response to changing conditions.

Table 32. TSMO strategies for managed lanes.

ID	TSMO Strategies	Description	Cooperation Class	Additional Benefit to Existing TSMO Strategy
7-1	**High-Occupancy Toll Lanes** Related strategies: Electronic Toll Collection (3-3), Variable Tolls (3-4)	This strategy involves any HOT lane that allows vehicles not meeting minimum occupancy requirements to use the lane by paying a toll.	A, B	Optimized HOT activation based on additional high-frequency traffic data. Granular toll rates. Tolls based on vehicle attributes and number of occupants.
7-2	**High-Occupancy Vehicle Lanes**	This strategy involves a preferential lane designated for exclusive use by vehicles with two or more occupants for all or part of a day, including a designated lane on a freeway, highway, street, or independent roadway on a separate right-of-way.	A	Number-of-occupants detected. Improved HOV effectiveness and optimization planning based on additional traffic data.
7-3	**Lanes Dedicated as Transit or Commercial Motor Vehicle Only** Related strategies: Digital Infrastructure Messaging (17-8), Roadside Truck Electronic Screening/Clearance (5-2)	This strategy focuses on lanes dedicated to transit or freight vehicles.	A, B, C	Ability to provide lane guidance to transit and trucks. Reduced need for infrastructure investments.

Table 33 presents TSMO strategies for road weather management that focus on providing users with a safe and efficient transportation system during and after weather events.

Table 33. TSMO strategies for road weather management.

ID	TSMO Strategies	Description	Cooperation Class	Additional Benefit to Existing TSMO Strategy
8-1	**En Route Weather Alerts and Pavement Condition Information** Related strategies: Multimodal Regional Traveler Information (12-1)	En route weather alerts and pavement-condition information involve active alerts based on a particular route.	A, B	More accurate location-based weather data. Improved safety for Cooperation Class B vehicles through in-vehicle notifications.
8-2	**Motorist Advisory and Warning Systems** Related strategies: Queue Warning (2-4), Multimodal Regional Traveler Information (12-1), Cooperative Weather-Responsive Conflict Management (17-5)	This strategy collects and processes data to develop warnings based on weather conditions.	A, B	Personalized advisories and warnings based on vehicle attributes. More accurate confirmation of hazard types. More timely warnings.
8-3	**Pretrip Condition Information and Forecast Systems** Related strategies: Predictive Traveler Information (12-3)	Pretrip condition information and forecast systems involve using weather data to predict conditions prior to a trip.	A, B	Improved weather predictions from additional weather data. Warnings based on vehicle type and route for Cooperation Class B vehicles.
8-4	**Route Optimization for Snowplows** Related strategy: Fleet Management (5-1)	This strategy involves dynamic optimization of snowplows based on traffic demand to minimize impact to a region.	A, B, C	Route optimization for snowplows based on additional traffic data. Increased roadway prioritization based on vehicle data.
8-5	**Winter Operations** Related strategy: Weather-Related Road Restrictions (8-6)	This strategy includes several activities that an organization performs to prepare or address adverse winter conditions, such as salting the roadway and removing snow.	A, B, C	Better operations from additional high-frequency data.
8-6	**Weather-Related Road Restrictions** Related strategies: Access Management (1-1), Digital Infrastructure Messaging (17-8), Roadside Truck Electronic Screening/Clearance (5-2), Winter Operations (8-5)	This strategy limits access to roads based on weather conditions.	A, B	Personalized warnings based on vehicle type and route for Cooperation Class B vehicles. Faster identification of roads that should be restricted based on weather conditions.

ID	TSMO Strategies	Description	Cooperation Class	Additional Benefit to Existing TSMO Strategy
8-7	**Weather-Responsive Traffic Signal Control** Related strategies: Adaptive Signal Timing (1-2), Cooperative Weather-Responsive Conflict Management (17-5)	This strategy adjusts signal controls based on current weather conditions.	A, B	Automatic adjustment based on more accurate location-based weather data. Ability to consider vehicle attributes.
8-8	**Weather-Related Vehicle Restrictions** Related strategies: Roadside Truck Electronic Screening/Clearance (5-2), Digital Infrastructure Messaging (17-8)	This strategy uses vehicle attributes to determine applicable weather-condition restrictions.	A, B	Improved identification of vehicles based on attributes. Personalized restrictions.
8-9	**Weather Speed Advisories** Related strategy: Speed Harmonization (Variable Speed Limits) (2-8)	Weather speed advisories are used as a safety application to advise drivers on a safe speed under the prevailing weather conditions.	A, B	Refined weather advisories based on additional weather data from connected vehicles. Improved targeted advisory delivery for Cooperation Class B vehicles.
8-10	**Weather-Responsive VSL Application** Related strategy: Speed Harmonization (Variable Speed Limits) (2-8)	This strategy consists of multiple roadside-monitoring and display trailers capable of detecting weather and traffic data.	A, B	Speed harmonization during adverse road weather events to streamline traffic and improve safety.

Table 34 presents TSMO strategies for safety management measures.

Table 34. TSMO strategies for safety management.

ID	TSMO Strategies	Description	Cooperation Class	Additional Benefit to Existing TSMO Strategy
9-1	**Bicycle Detection/Warning** Related strategy: Intersection Warnings (9-3)	This strategy includes a detection and warning system to alert drivers of potential cyclists.	A, B	Faster object detection alerting. Improved targeted warnings based on location, speed, and vehicle attributes.
9-2	**Geometry Warnings**	This strategy includes a warning system to alert drivers of geometric dangers, such as a sharp curve.	A, B	Identification of geometric dangers. Personalized, targeted warnings based on vehicle attributes.
9-3	**Intersection Warnings** Related strategies: Bicycle Detection/Warning (9-1), Pedestrian Detection/Warning (9-4), Red-Light Violation Warning (16-5), Intersection Conflict Management (17-12)	This strategy involves warning systems at intersections to provide supplemental safety-related information, such as traffic-light status.	A, B	Benefit from providing fast notifications to each vehicle depending on location and vehicle attributes.
9-4	**Pedestrian Detection/Warning** Related strategy: Intersection Warnings (9-3)	This strategy includes a detection and warning system to alert drivers to pedestrians crossing the road.	A, B	Improved pedestrian detection. Targeted warnings.

Table 35 presents TSMO strategies for special event management, including sporting events, concerts, festivals, and conventions occurring at permanent multiuse venues (e.g., arenas, stadiums, racetracks, fairgrounds, amphitheaters, convention centers).

Table 35. TSMO strategies for special event management.

ID	TSMO Strategies	Description	Cooperation Class	Additional Benefit to Existing TSMO Strategy
10-1	**Special Event Management** Related strategies: Mass Media Communication (18-4), Shoulder Lanes (2-9), Traffic-Incident Management (11-2)	This strategy involves changing related strategies to account for a planned event based on anticipated impacts on traffic flow.	A, B, C	Improved traffic routing. Improved predictions based on high-resolution traffic data. Additional safety from in-vehicle guidance, particularly for Cooperation Class B vehicles.

Table 36 presents TSMO strategies for TIM, which consists of a planned and coordinated multidisciplinary process to detect, respond to, and clear traffic incidents so that traffic flow may be restored as safely and quickly as possible.

Table 36. TSMO strategies for TIM.

ID	TSMO Strategies	Description	Cooperation Class	Additional Benefit to Existing TSMO Strategy
11-1	**Full-Function Service Patrols** Related strategy: Fleet Management (5-1)	Service patrols are usually operated directly by or under contract to a State DOT. As such, the patrol can be the onscene "eyes and ears" for a TMC, increasing the promptness and accuracy of information about an incident's impact to the traveling public.	A, B	Faster response time. Personalized vehicle guidance. Improved routing.
11-2	**Traffic-Incident Management** Related strategies: Lane Use Control (2-3), Shoulder Lanes (2-9), Computer-Aided Dispatch (CAD) Integration With Traffic Management Center (TMC) Operations (18-1), Decision Support System (6-1), Multimodal Regional Traveler Information (12-1), Emergency Response (4-3), Incident Scene Prearrival Staging Guidance For Emergency Responders (RESP-STG) (16-4), Dynamic Route Guidance (17-10), Disabled Vehicle Beacon (17-9), Lane Clear (17-13), Safety Buffer (17-18), Emergency Path Clearance (17-11), Quick Clearance Policies (18-2), Wrecker Response Contracts (18-3), Special Event Management (10-1), Freeway/Arterial ICM (6-2)	TIM consists of a planned and coordinated multidisciplinary process to detect, respond to, and clear traffic incidents so that traffic flow may be restored as safely and quickly as possible. Applied effectively, TIM reduces the duration and impacts of traffic incidents and improves the safety of motorists, crash victims, and emergency responders.	A, B, C	Optimized response based on additional traffic data. Improved onsite monitoring. Increased safety and advanced notifications based on Cooperation Class B cooperation. Improved safety and mobility. Increased productivity.

DOT = department of transportation.

Table 37 presents TSMO strategies for traveler information, designed to provide transportation system users with the information they need to choose the safest and most efficient mode and route of travel.

Table 37. TSMO strategies for traveler information.

ID	TSMO Strategies	Description	Cooperation Class	Additional Benefit to Existing TSMO Strategy
12-1	**Multimodal Regional Traveler Information** Related strategies: En Route Weather Alerts and Pavement Condition Information (8-1), Traffic-Incident Management (11-2), Real-Time Traffic Monitoring (2-7), Special Event Management (10-1), Real-Time Transit Arrival Information (12-4), Motorist Advisory and Warning Systems (8-2), Queue Warning (2-4)	This strategy provides real-time information to travelers, allowing them to reschedule or reroute trips away from traffic incidents, construction zones, road closures, and transit service changes, thereby improving travel time reliability, safety, and quality of life.	A, B	High-resolution real-time traffic and weather data. Improved safety messages based on additional data attributes. Personalized traveler information based on O-D and vehicle attributes.
12-2	**Parking Availability Information and Guidance** Related strategies: none	This strategy uses parking-space detection technology to gather and disseminate information to assist drivers in finding parking in a safe and efficient manner.	B	Improved parking availability identification. Personalized parking information based on vehicle attributes or expected time of arrival. Increased ability to predict parking availability.
12-3	**Predictive Traveler Information** Related strategy: Pretrip Condition Information and Forecast Systems (8-3)	This strategy uses historical and real-time data to predict and notify the driver regarding anticipated travel times.	A, B	Additional high-resolution data for machine learning prediction applications. Improved safety messages based on additional data attributes.
12-4	**Real-Time Transit Arrival Information** Related strategies: Real-Time Traffic Monitoring (2-7), Multimodal Regional Traveler Information (12-1), Advanced Transit Operations (14-1)	This strategy uses historical and real-time data to predict transit arrival times.	A, B	Improved transit arrival predictions from additional data.

O-D = origin–destination.

Table 38 presents TSMO strategies for travel demand management, which provides users with effective travel choices to shift or reduce the demand for travel under congested conditions.

Table 38. TSMO strategies for travel demand management.

ID	TSMO Strategies	Description	Cooperation Class	Additional Benefit to Existing TSMO Strategy
13-1	**Commuter Incentives** Related strategy: none	This strategy involves incentives for commuters to choose alternate transportation methods, such as transit or carpools, to alleviate congestion in a particular location.	B	Enhanced ridership.
13-2	**First-Mile/Last-Mile Connectivity** Related strategy: none	This strategy uses ride-shares, bikes, scooters, and so on, to provide transportation between parking or transit locations and final destinations.	B	Enhanced first-mile/last-mile connections by using O-D data.
13-3	**Rideshare System** Related strategy: none	This strategy encourages the use of third-party rideshare systems.	A, B	Improved rideshare opportunities based on O-D information.

O-D = origin–destination.

Table 39 presents TSMO strategies for transit operations and management, which focus on the operation and management of the transit system in a safe and efficient manner.

Table 39. TSMO strategies for transit operations and management.

ID	TSMO Strategies	Description	Cooperation Class	Additional Benefit to Existing TSMO Strategy
14-1	**Advanced Transit Operations** Related strategies: Real-Time Transit Arrival Information (12-4), High-Performance Transit (14-2)	This strategy involves operational techniques intended to maximize transit efficiency.	A, B	Improved operations based on additional traffic data. Improved safety through warning systems.
14-2	**High-Performance Transit** Related strategies: Advanced Transit Operations (14-1), Real-Time Transit Arrival Information (12-1)	This approach involves the development and use of high-performance strategies to encourage commuters to use transit.	A, B	Optimization of transit schedules based on additional traffic demands and O-D data.

O-D = origin–destination.

Table 40 presents TSMO strategies for WZM, which involves organizing and operating areas under construction to minimize traffic delays, maintain safety for workers as well as travelers, and accomplish the work efficiently.

Table 40. TSMO strategies for WZM.

ID	TSMO Strategies	Description	Cooperation Class	Additional Benefit to Existing TSMO Strategy
15-1	**Work-zone Management** Related strategies: Lane-Use Control (2-3), Shoulder Lanes (2-9), Agency Coordination and Integration (18-9)	This strategy focuses on managing traffic during construction to minimize traffic delays, maintain motorist and worker safety, complete roadwork in a timely manner, and maintain access for businesses and residents.	A, B, C	Improved work-zone safety. Personalized warnings based on vehicle attributes. Improved work-zone vehicle guidance.

Table 41 presents other TSMO strategies.

Table 41. Other TSMO strategies.

ID	TSMO Strategies	Description	Cooperation Class	Additional Benefit to Existing TSMO Strategy
16-1	**Asset Management** Related strategies: Freeway/Arterial ICM (6-2), TIM (11-2)	Asset management is the strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets.	A, B	Improved traffic management.
16-2	**Bottleneck Mitigation** Related strategies: none	This strategy involves changes to alleviate bottleneck locations within a corridor/region. Recurring bottlenecks often require physical changes to the roadway. Temporary management of a bottleneck issue can be done by using cooperative vehicle data.	A, B, C	Improved bottleneck alleviation.
16-3	**Data Marts and Data Warehouses** Related strategies: all	This strategy designs and builds a data warehouse to collect data that can be used by most other strategies.	A, B	Improved strategies by using high-resolution data. Enable data sharing between agencies.
16-4	**Incident Scene Prearrival Staging Guidance for Emergency Responders (RESP-STG)** Related strategies: Emergency Response (4-3), Traffic-Incident Management (11-2), Emergency Path Clearance (17-11), Lane Clear (17-13), Safety Buffer (17-18)	This strategy involves guidance from the TMS regarding coordination at the incident scene by using connected vehicle data.	A, B	Improved emergency response. Increased safety.

ID	TSMO Strategies	Description	Cooperation Class	Additional Benefit to Existing TSMO Strategy
16-5	**Red-Light Violation Warning** Related strategy: Intersection Warnings (9-3)	This strategy provides advanced warning to vehicles based on their speed as they approach intersections with a red traffic signal status.	A, B	Increased safety.

Table 42 presents the potential new TSMO strategies and relationship to CDA.

Table 42. Potential new TSMO strategies and relationship to CDA data.

ID	TSMO Strategies	Description	Cooperation Class
17-1	**Automated Maintenance and Fleet-Management Systems** Related strategy: Fleet Management (5-1)	This strategy automates the scheduling of vehicle maintenance, ordering materials, and deploying assets to the required locations.	A, B
17-2	**Automated Maintenance Decision Support System** Related strategy: Decision Support System (6-1)	This strategy uses, optimizes, and automates maintenance decision support systems through cooperative automation.	A, B
17-3	**Break Long Queues on Arterials** Related strategy: Queue Warning (2-4)	This strategy supports breaking long queues on arterials to allow side-street vehicle crossing/merging.	B, C
17-4	**Cooperative Lane-Balancing** Related strategy: none	This strategy uses the interaction between TMSs and CDA to "lane-balance" the traffic loads across lanes.	B, C
17-5	**Cooperative Weather-Responsive Conflict Management** Related strategies: Weather-Responsive Traffic-Signal Control (8-7), Motorist Advisory and Warning Systems (8-2)	This strategy enables cooperative weather-responsive conflict management for intersections between infrastructure and CDA vehicles.	B, C
17-6	**Curbside Management** Related strategy: Access Management (1-1)	This strategy manages and optimizes curb demand to provide reliable access.	B, C
17-7	**Dedicated ADS Lanes** Related strategies: none	This strategy dedicates a lane to ADS to encourage and optimize the benefits to support freeway capacity.	A, B, C
17-8	**Digital Infrastructure Messaging** Related strategy: all	This strategy involves TMSs sharing regulatory information digitally within a geofenced location based on vehicle attributes to support TSMO strategies.	A, B
17-9	**Disabled Vehicle Beacon** Related strategy: Traffic-Incident Management (11-2)	This strategy uses cooperative communication to broadcast information regarding a disabled vehicle approaching CDA vehicles.	A

ID	TSMO Strategies	Description	Cooperation Class
17-10	**Dynamic Route Guidance** Related strategy: Traffic-Incident Management (11-2)	Dynamic route guidance is a strategy that augments a user's navigation with real-time traffic, transit, and road condition information from a TMS or third-party company to assist with route guidance. This strategy may also include instructions and guidance to balance traffic flows (dynamic traffic assignment).	B
17-11	**Emergency Path Clearance** Related strategies: Traffic-Incident Management (11-2), Emergency Response (4-3), Safety Buffer (17-18), Lane Clear (17-13), Incident Scene Prearrival Staging Guidance for Emergency Responders (RESP-STG) (16-4)	This strategy involves clearing a path ahead to decrease response time for emergency responders.	B, C
17-12	**Intersection Conflict Management** Related strategy: Intersection Warnings (9-3)	This strategy uses cooperative vehicle data to give advanced warning of potential collisions at intersections. The strategy may also include communications with CDA to prevent collisions at intersections by enhanced communications, negotiations, and predictive path trajectory sharing between other vehicles and the infrastructure.	B, C
17-13	**Lane Clear** Related strategies: Traffic-Incident Management (11-2), Safety Buffer (17-18), Emergency Path Clearance (17-11), Emergency Response (4-3), Incident Scene Prearrival Staging Guidance for Emergency Responders (RESP-STG) (16-4)	This strategy involves safe lane clearing using location-based data and CDA to assist in clearing a lane for emergency vehicles.	B, C
17-14	**Lateral Vehicle Formations** Related strategy: Speed Harmonization (2-8)	This strategy coordinates the operation of vehicles traveling side-by-side in adjacent lanes (sometimes referred to as lateral platooning). Variable speed limits.	B, C
17-15	**Perceived Lane Capacity** Related strategies: none	This strategy provides lane-level speed data and occupancy data from perception sensors shared from CDA vehicles.	A, B
17-16	**Railroad-Crossing Conflict Management** Related strategies: none	This strategy uses CDA to coordinate potential railroad-crossing conflicts.	B
17-17	**Safe Stop** Related strategies: none	This strategy involves law enforcement safely stopping ADS or CDA vehicles.	B, C
17-18	**Safety Buffer** Related strategies: Traffic-Incident Management (11-2), Lane Clear (17-13), Emergency Path Clearance (17-11), Emergency Response (4-3), Incident Scene Prearrival Staging Guidance for Emergency Responders (RESP-STG) (16-4)	This strategy uses cooperative communications to broadcast a safety-zone geofence around first responders to enforce Move-Over laws.	B, C

ID	TSMO Strategies	Description	Cooperation Class
17-19	**Vehicle Platooning** Related strategies: none	This strategy coordinates the operation of vehicles traveling very closely behind each other at high speeds.	B, C

Table 43 presents TSMO strategies not expected to be impacted by CDA.

Table 43. TSMO strategies not expected to be impacted by CDA data.

ID	TSMO Strategies	Description
18-1	**Computer-Aided Dispatch Integration with Operations** Related strategies: Traffic-Incident Management (11-2), Emergency Response (4-3)	This strategy integrates data between TMSs and CAD databases; it helps incident responders to collaborate, reducing response time and aiding in incident management.
18-2	**Quick-Clearance** Related strategy: Traffic-Incident Management (11-2)	Quick-clearance policies provide a set of guidelines to ensure the safe, efficient removal of vehicles involved in an incident from impeding traffic.
18-3	**Wrecker Response Contracts** Related strategy: Traffic-Incident Management (11-2)	This strategy pertains to contracts with towing companies for removal of wrecked or disabled vehicles and debris from the incident scene.
18-4	**Mass Media Communication** Related strategies: Evacuation Management (4-1), Special Event Management (10-1)	This strategy involves traditional advertising methods, such as radio, TV, or Internet, to reach drivers with safety warnings.
18-5	**Traveler Information Marketing Campaigns** Related strategies: none	This strategy publishes and markets traveler information through a variety of means including print, Internet, and other media outlets to ensure travelers are aware of available options.
18-6	**Employer Programs** Related strategies: none	This strategy involves employers assisting staff with subsidized travel options to encourage the use of public transport, carpools, and so on.
18-7	**Telecommuting** Related strategies: none	This strategy involves individuals working remotely.
18-8	**Urban Centers, Corridor, and Industrial Area Investments** Related strategies: none	This strategy involves roadway design improvements.
18-9	**Agency Coordination and Integration** Related strategies: Evacuation Management (4-1), Freeway/Arterial Integrated Corridor Management (6-2), Road Weather Management (8)	Agency coordination and integration involves communications between departments to optimize relevant regional strategies.
18-10	**Unmanned Aerial Systems Detection and Monitoring** Related strategies: none	This strategy uses tethered and relay drones to detect and monitor incidents.

CAD = computer-aided dispatch.

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