High-Level Concept of Operations: Examination of the Relationships Between Transportation Systems Management and Operations Strategies and Cooperative Driving Automation

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FOREWORD

The Turner-Fairbank Highway Research Center performs advanced research in several areas of transportation technology for the Federal Highway Administration (FHWA). The Office of Operations Research and Development (HRDO) focuses on improving operations-related technology through research, development, and testing.

This report presents a high-level concept of operations (ConOps) in support of the CARMA Platform℠ sponsored by FHWA HRDO. Developing this ConOps is an initial step in the current CARMA℠ effort to define and develop testable use cases that demonstrate how cooperative driving automation capabilities can be integrated with transportation systems management and operations strategies. 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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Operations Research and Development

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16. Abstract
This report explores the relationships between transportation systems management and operations (TSMO) strategies and cooperative driving automation (CDA). It presents a high-level concept of operations (ConOps) in support of the CARMA Platform℠ sponsored by the Federal Highway Administration Office of Operations Research and Development. Developing this ConOps is an initial step in the current CARMA℠ effort to define and develop testable use cases that demonstrate how CDA capabilities can be integrated with TSMO strategies. The ConOps first discusses the traditional TSMO strategies for operating and managing the transportation infrastructure. It then identifies, at a high level, those strategies expected to be impacted by the introduction of CDA technologies. Next, from among this nexus of TSMO strategies, the ConOps focuses on four use cases—basic travel, traffic-incident management, road-weather management, and work-zone management—and explores the framework of those relationships in greater detail. The ConOps also describes whether—and, if applicable, how—CDA will impact existing TSMO use case activities. This mapping accounts for both the levels of vehicle automation and classes of vehicle cooperation.

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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

ACC	adaptive cruise control
ADS	automated driving system
AI	artificial intelligence
ATM	active traffic management
ATMS	active traffic management system
CACC	cooperative adaptive cruise control
CDA	cooperative driving automation
CCTV	closed-circuit television
ConOps	concept of operations
DOT	department of transportation
DDT	dynamic driving task
DMS	dynamic message sign
DSRC	dedicated short-range communication
FHWA	Federal Highway Administration
O-D	origin–destination
ODD	operational design domain
OEM	Original Equipment Manufacturer
OSS	open-source software
RSU	roadside unit
RWIS	road weather information stations
RWM	road-weather management
SOP	standard operating procedure
SUV	sport utility vehicle
TIM	traffic-incident management
TMC	traffic management center
TMS	transportation management service
TSMO	transportation systems management and operations
V2V	vehicle-to-vehicle
V2X	vehicle-to-everything
VMS	variable message sign
WZM	work-zone management

CHAPTER 1. INTRODUCTION

PURPOSE

This report explores the relationships between transportation systems management and operations (TSMO) strategies and cooperative driving automation (CDA). This report presents a high-level concept of operations (ConOps) in support of the CARMA Platform℠ sponsored by the Federal Highway Administration (FHWA) Office of Operations Research and Development. Developing this ConOps is an initial step in the CARMA℠ effort to define and develop testable use cases that demonstrate how CDA capabilities can be integrated with TSMO strategies.

The high-level ConOps presented in this report examines the essentials in the TSMO/CDA relationship—first exploring the traditional TSMO strategies for operating and managing the transportation infrastructure, then identifying those strategies expected to be impacted by the introduction of CDA technologies. Next, the high-level ConOps focuses on four sets of use cases—basic travel, traffic-incident management (TIM), road-weather management (RWM), and work-zone management (WZM)—and explores the framework of those relationships in greater detail. More specifically, each use case framework identifies the actions the entity responsible for TSMO activities (e.g., an organization operating a transportation management service [TMS]) performs to achieve the TSMO strategy. The high-level ConOps also describes whether—and, if applicable, how—CDA impacts existing TSMO use case activities. This mapping accounts for both the levels of vehicle automation and classes of vehicle cooperation.

The high-level ConOps was reviewed, critiqued, and validated by FHWA and multiple stakeholder review teams. Following completion of these reviews, the use case frameworks were revised as needed, and the high-level ConOps was updated accordingly. A detailed ConOps was also prepared, which lays out the priority situations under each use case. The situational descriptions are sufficiently detailed to allow for building associated algorithms, integrating the algorithms into CARMA, and operationally testing the algorithms under proving-ground or onroad conditions.

The CARMA effort examines and tests the emerging roles and responsibilities of TSMO managers and operators as CDA-equipped vehicles become more prevalent on the Nation's roadways. This report seeks to answer some basic questions, including which existing TSMO functions will need to be modified and what new TSMO functions and capabilities will be required to accommodate the integration of CDA technologies. The challenges for TSMO managers and operators are exacerbated by the expectation that the Nation is entering a period during which both traditional and CDA-equipped vehicles will traverse the roadways. TSMO managers and operators expect CDA-equipped vehicles to grow in numbers and levels of automation into the foreseeable future.

CONTENTS

The high-level ConOps provides a preliminary framework for conceptualizing the interactions between TSMO and CDA and includes the following components:

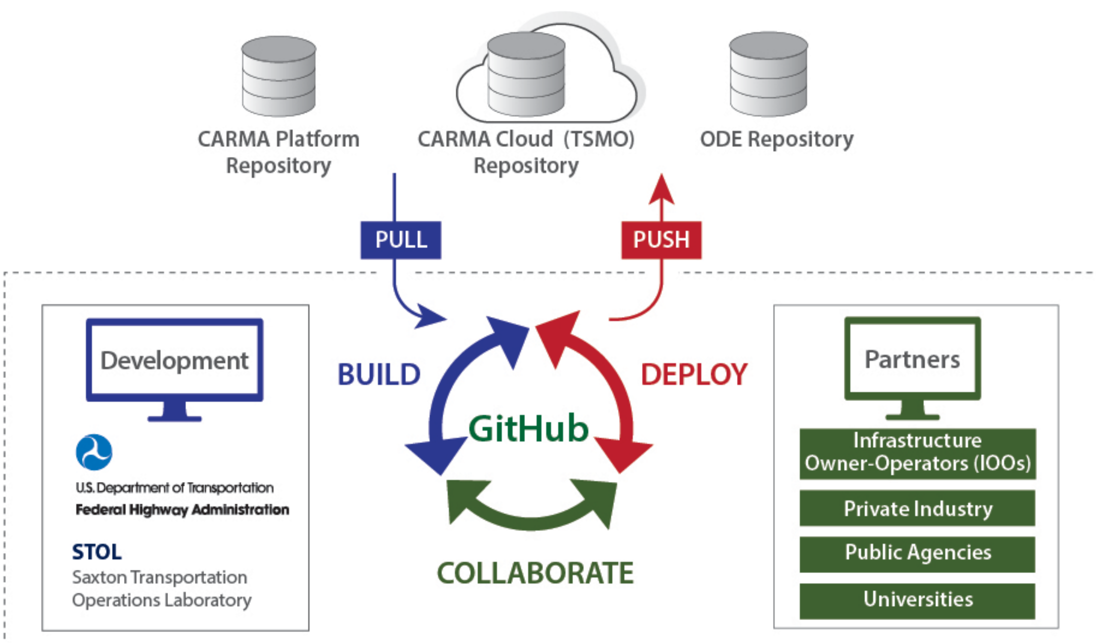
- Terminology—describes the specialized terminology used in this report.
- Strategies table—presents a comprehensive list, in tabular format, of TSMO strategies and their relationships to CDA.
- Data table—augments the strategies table by identifying the specific types of data needed to implement the corresponding strategies.
- Use case framework—depicts the framework for interactions between TSMO and CDA, including input and output diagrams. The four use cases are examined across a series of matrices.
- Scenarios—illustrates the key impacts and benefits of the four use cases using operational scenarios.

CHAPTER 2. TERMINOLOGY

CARMA

FHWA developed the innovative CARMA Platform to encourage collaboration among interested stakeholders including State and local agencies and academia, with the goal of improving transportation efficiency and safety. FHWA's interest in advancing TSMO strategies with CDA focuses on how traffic can move more efficiently on the roadway infrastructure.

CARMA enables CDA technologies to facilitate cooperative tactical maneuvers with other vehicles and roadway infrastructure. CARMA was designed using open-source software (OSS) and is available on GitHub (figure 1). The unique platform was created to be vehicle- and technology-agnostic.



Source: FHWA.
ODE = operational data environment.

Figure 1. Illustration. GitHub repository for CARMA.

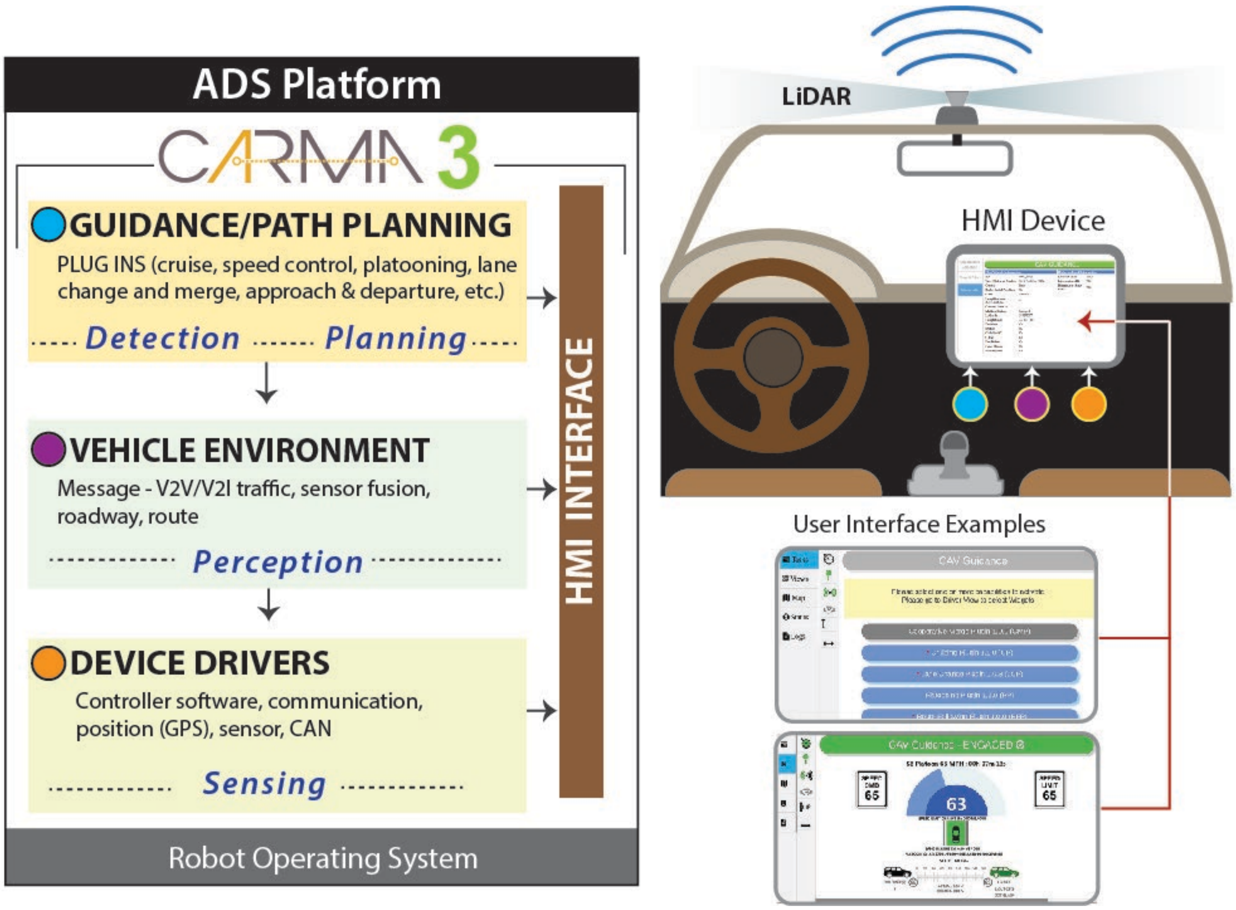
The first generation of CARMA, CARMA1, was initiated in 2014 to develop and implement a proof-of-concept software platform. The second generation of CARMA, CARMA2, which was initiated in 2016, moved to a robot operating system architecture that enabled cooperative automated driving plugins. The development of the third generation of CARMA, CARMA3, began in 2018. Work to develop the CARMA Platform began during second-generation development and has migrated to third-generation development.

The CARMA Platform includes plugins that support the following cooperative driving tactics:

- Cruising—recognize and follow the speed limit.
- Yield—slow down or completely stop a vehicle to avoid a collision.
- Lane change and merge—coordinate with vehicles in a lane to the left or right to make space to merge and change lanes safely.
- Platooning—enable collaboration between vehicles at close range to reduce fuel consumption, reduce delay at intersections, and make more efficient use of roadways.
- Speed harmonization—follow dynamic speed commands from a cloud server that measures traffic and determines upstream speeds to minimize traffic jams and limit backend congestion.

A cloud-based OSS, CARMA Cloud℠, which enables infrastructure cooperation with automated driving technology through TSMO, is under development.

Developing TSMO and CDA use cases is part of the CARMA3 effort. The platform is being developed using an agile software development process to facilitate collaboration with the stakeholder community. An illustration of the CARMA3 architecture is shown in figure 2.



Source: FHWA.
HMI = human–machine interface; CAN = Controller Area Network; LiDAR = light detection and ranging; CAV = cooperative and autonomous vehicle; V2I = vehicle-to-infrastructure; GPS = Global Positioning System; V2V = vehicle-to-vehicle.

Figure 2. Illustration. CARMA3 architecture.

LEVELS OF AUTOMATION

The levels of automation for onroad motor vehicles are defined by SAE International in J3016-201806, *Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles*.[(2)] The levels of automation described in this section were adapted from J3016-201806.

Level 0: no driving automation—the driver controls the vehicle completely without any support from a driver-assistance system.

Level 1: driver assistance—an automated system on the vehicle sometimes assists the driver in performing some elements of the driving task. Many vehicle manufacturers offer Level 1 automation. Adaptive cruise control (ACC) is a Level 1 technology.

At Level 1, a computer can control either steering or acceleration/braking but is not programmed to do both at the same time. Regardless, the driver still has full responsibility to monitor road situations and assume all driving functions when the driver-assistance system is not active.

Level 1 driver-assistance systems include the following functionality:

- ACC automatically adapts speed to maintain a safe distance from the vehicles ahead.
- Autonomous emergency braking detects an obstacle, warns the driver, or automatically brakes to avoid or mitigate a crash.
- Lane detection uses a forward-facing camera to detect lane markings on the road.
- Lane-keeping assist combines a forward-facing camera to detect lane markings with an electric steering system, keeping the vehicle in the center of the lane.
- Parking-assistance systems help drivers park; some systems automatically perform the entire job, while others provide guidance so the driver knows when to turn the steering wheel and when to stop.
- Parking-line-detection systems detect markers on the road surface to determine the precise location of parking spaces.
- Cooperative adaptive cruise control (CACC) automatically adapts speed to maintain a safe distance from the vehicles ahead by receiving information from forward vehicles while in CACC driving mode.

Level 2: partial driving automation—this functionality is already a reality. Semiautonomous driver-assistance systems, such as the steering- and lane-control assistant (including traffic-jam assistant), make daily driving easier and safer. These systems can brake automatically, accelerate/decelerate and, unlike Level 1, can simultaneously assume steering control. One main difference between Level 1 and Level 2 automation is that, in Level 2, CDA-equipped vehicles communicate with each other. In Level 2, the driver remains in control of the vehicle and must pay attention to traffic.

Level 3: conditional driving automation—drivers can turn their attention away from the road under certain conditions (i.e., when circumstances permit, drivers can hand over complete control to the vehicle). However, the driver must be ready to resume control of the vehicle within seconds of being prompted (e.g., while traversing locations undergoing roadway construction).

Level 4: high driving automation—this is considered fully autonomous driving, although the driver may still request control if the vehicle has a cockpit/steering wheel. In Level 4, the vehicle manages most driving situations independently, including complex urban circumstances (e.g., areas with roadway construction or maintenance activities). The vehicle may, depending on its capabilities, provide the driver with the option to take control of the vehicle or will safely exit the roadway and stop if one or more of the following situations occurs:

- Operating outside a defined geofenced area (e.g., paved streets in a defined area of town).
- Operating during adverse weather (e.g., falling snow, snow-packed roads, intense rain, thick fog).
- Exceeding a maximum speed limit (e.g., vehicles limited to 35 mph can travel on most streets but not on roadways posted at 40 mph and above).

The situational limitations for a specific Level 4 vehicle are predefined by the Original Equipment Manufacturer (OEM).

Level 5: full driving automation (driverless)—unlike Level 3 and Level 4, full driving automation supports driverless operation under virtually all conditions. Here, everyone in the vehicle is a passenger and, theoretically, no one needs a driver's license. Vehicles at this level must meet stringent safety requirements.

COOPERATION CLASSES

This high-level ConOps framework distinguishes between levels of vehicle automation and classes of vehicle cooperation. The Cooperation Classes are defined as follows:

- Class A—Here I am and what I see. An entity's cooperative capabilities are limited to handling current status information about the entities involved.
- Class B—This is what I plan to do. Cooperation among entities is based on sharing both current status information and future intentions so that entities can work around each other with foresight.
- Class C—Let's do this together. Cooperation among entities extends beyond just understanding others' intentions, but interactively planning joint activities that can be performed in concert.
- Class D—I will do as directed. Cooperation among entities to direct other's actions.

Table 1 shows the interaction of the cooperation classes with vehicles of different levels of automation. Cooperative automation includes all combinations of cooperation and SAE levels. Cooperation Class A through Class C assume the presence of two-way communications, with the degree of information exchange varying according to the level of automation and class of cooperation.

During the development of this report, SAE On-Road Automated Driving committee was still developing a taxonomy for CDA, SAE J3216. The concepts for cooperation classes presented in this report are for conceptual use and mostly match with the definitions of the classes as defined in SAE J3216.

Table 1. Overview of SAE levels and cooperation classes.

No Automation		Partial Automation of DDT			Complete Automation of DDT		
		SAE Level 0: No Driving Automation (Human Does All Driving)	**SAE Level 1: Driver Assistance (Longitudinal or Lateral Vehicle Motion Control)**	**SAE Level 2: Partial Driving Automation (Longitudinal and Lateral Vehicle Motion Control)**	**SAE Level 3: Conditional Driving Automation**	**SAE Level 4: High Driving Automation**	**SAE Level 5: Full Driving Automation**
No Cooperative Automation		E.g., signage, TCD	Relies on driver to complete the DDT and to supervise feature performance in real time		Relies on ADS to perform complete DDT under defined conditions (fallback condition performance varies between levels)		
SAE Class A: Status Sharing	**Here I am and what I see**	E.g., brake lights, traffic signal	Potential for improved object and event detection*		Potential for improved object and event detection**		
SAE Class B: Intent Sharing	**This is what I plan to do**	E.g., turn signal, merge	Potential for improved object and event prediction*		Potential for improved object and event prediction**		
SAE Class C: Agreement Seeking	**Let's do this together**	E.g., hand signals, merge	N/A		C-ADS designed to attain mutual goals through coordinated actions		
SAE Class D: Prescriptive	**I will do as directed**	E.g., hand signals, lane assignment by officials	N/A		C-ADS designed to accept and adhere to a command		

*Improved object and event detection and prediction through CDA Class A and B status and intent sharing may not always be realized, given that Level 1 and 2 driving automation features may be overridden by the driver at any time, and otherwise have limited sensing capabilities compared to Level 3, 4 and 5 ADS-operated vehicles.

**Class A and B communications are one of many inputs to an ADS's object and event detection and prediction capability, which may not be improved by CDA message.

C-ADS = cooperative automated driving systems; DDT = dynamic driving task; N/A = not applicable; TCD = traffic-control device.

In the case of "No Cooperative Automation," the vehicle does not interact with the surrounding vehicles or infrastructure; the vehicle must be able to navigate and visually interpret traditional modes of information dissemination, even at high levels of automation. A Class A vehicle has basic situational awareness and the capability to share and receive status information but lacks the capability to predict what vehicles in its vicinity will do. A Class B vehicle possesses expanded situational awareness because it is capable of sharing information about its plans and gathering information on the intended actions of other vehicles; this allows the vehicle to perform coordinated maneuvers. In contrast, Class C vehicles not only know what each other are planning to do but are able to interact collaboratively, negotiating together to execute cooperative maneuvers—thereby optimizing interactions with the surrounding traffic.

TSMO FUNCTIONS

TSMO-focused operational activities refer to those sets of functions that TMSs typically perform in conjunction with recurring use cases, including managing incidents, planned special events, weather events, work zones, and so on. Because the utility and details of individual operational actions vary by use case, these actions are identified and examined under the use cases in chapter 3.

The specific data needed from a TMS must consider driving tasks performed by the driver versus those carried out by the onboard CDA. A summary of the relationships between the driver and the automated driving system (ADS), across each of the five Automation Levels, is depicted in table 2.

Table 2 identifies specialized terminology, which is briefly described in the remainder of this section. For full definitions of these terms, refer to the SAE J3016-201806 standard document.

Table 2. SAE standard J3016-201806 Automation Levels and driver versus vehicle system driving activities.

Automation Level	Name	DDT Sustained Lateral and Longitudinal Vehicle Motion Control	DDT Object and Event Detection and Response	DDT Fallback	Operational Design Domain
0	No driving automation	Driver*	Driver*	Driver*	N/A
1	Driver assistance	Driver and system	Driver*	Driver*	Limited
2	Partial driving automation	System	Driver*	Driver*	Limited
3	Conditional driving automation	System	System	Fallback-ready user (becomes the driver during fallback)	Limited
4	High driving automation	System	System	System	Limited
5	Full driving automation	System	System	System	Unlimited

*Tasks performed by the driver as opposed to those performed by the system.
DDT = dynamic driving task; N/A = not applicable.

Dynamic driving task (DDT): describes the real-time functions a vehicle must be able to perform to safely operate on a roadway and within traffic regardless of the Automation Level of other nearby vehicles (see J3016-201806, section 3.13). Examples of these real-time functions include the following:

- Lateral vehicle motion control.
- Accelerating/decelerating (i.e., longitudinal vehicle motion control).
- Detecting of and safely responding to objects and events in the path of the vehicle.
- Planning maneuvers and making other vehicles aware of the planned maneuvers.

Note that active safety systems, such as lane control, emergency braking, and others, are not considered parts of a DDT because they provide only temporary interventions and do not support DDTs on a continuous and sustained basis.

DDT fallback: describes the functions a driver must perform after a performance-related failure of the ADS, after the ADS-related operational design domain (ODD) conditions are no longer valid, or other failure has occurred (see J3016-201806, section 3.14). Examples of the functions a driver must perform include the following:

- Taking control of the vehicle should situations arise where the vehicle's ADS cannot safely perform.
- Performing an ADS function that brings the vehicle to a safe position, such as moving to the shoulder without driver intervention (automation Level 4 and Level 5).

Object and event detection and response: a subset of DDT that describes the detection, recognition, and classification of objects and events and the responses performed by the ADS (see J3016-201806, section 3.20).

ODD: describes the conditions and circumstances under which an ADS is designed to operate (see J3016-201806, section 3.22). This includes environmental, geographical, and time-of-day restrictions and required presence/absence of traffic and/or roadway characteristics. The latter might include an ADS function that restricts the operation of a vehicle to the following situations:

- Access-controlled highways.
- Low-speed traffic.
- Fair weather conditions.
- Geofenced areas encompassing specific routes.
- Specific time of day (e.g., daylight operation only).
- Any combinations of the previous restrictions.

The asterisks in table 2 indicate tasks performed by the driver as opposed to those performed by the system. The previously listed tasks and those to the left of the red line are driver-performed tasks, while those below and to the right are system-managed tasks.

The driver performs part or all the DDT for Level 0, Level 1, and Level 2.

The ADS performs the entire DDT (while engaged) for Level 3, Level 4, and Level 5.

ASSUMPTIONS

The material presented in this report is predicated on several key underlying assumptions. These assumptions include the following:

- TMSs need to support operational roadway activities in a mixed-use environment populated both by traditional and automated vehicles with various cooperation capabilities.
- TSMO strategies currently supported by TMSs will continue to be functional in a mixed-use environment, although many of the strategies will be enhanced by the availability of CDA technologies. The type of data and its range, quality, reliability, and mechanisms for delivery will change as CDA technologies become more commonplace. Additionally, new TSMO strategies will be made possible by the advent of CDA technologies.
- CDA-related policy decisions, such as whether an instruction to reduce speed is executed instantly when a new speed-limit zone is reached or harmonized gradually over time or distance, are deferred for now and will be decided later.
- Vehicles capable of vehicle-to-vehicle (V2V) cooperation will be present on the transportation network. The following examples demonstrate how V2V cooperation will enhance overall operational performance from a TMS perspective:
    - Ramp-metering operations, including weaving into mainline traffic, will be performed more efficiently when a high density of CDA V2V-capable vehicles is present. The TMS would receive location-specific data on the actions performed by vehicles due to their direct interactions; these data could be used to plan road geometry improvements (e.g., near-miss evaluations, extending merging areas).
    - A work zone lacked the presence of a roadside unit (RSU) to manage traffic conditions. Instead, a suitably equipped responder vehicle could act as the RSU, informing oncoming vehicles within a geofenced area of the traffic conditions and necessary maneuvers. This could happen directly or by a process of hopping, whereby the work-zone data are received by departing vehicles from the broadcasting responder vehicle and then transmitted to upstream vehicles approaching the work zone.

CHAPTER 3. KEY TSMO STRATEGIES AND THEIR RELATIONSHIPS TO CDA

INTRODUCTION

This chapter explores the relationships between TSMO strategies and CDA, highlighting the strategies employed by transportation agencies to optimize the performance (i.e., safety, mobility, and reliability) of existing transportation facilities and considering the utility of the strategies when deployed in a CDA environment. The tables in this chapter, which detail the relationships mentioned earlier, were developed as an output of an in-depth literature search of Federal, State, and local documents that identified the TSMO activities and related strategies.

The TSMO strategies presented here are profiled in tabular format in relation to CDA (Cooperation Class A through Class C). The case with no cooperative automation is not considered since no information is exchanged between the entities in this class; in the no cooperative automation case, vehicles continue to receive information via traditional roadside devices (e.g., dynamic message signs [DMSs]).

The TSMO strategies are examined in three parts as follows:

- TSMO strategies currently in the marketplace that are likely to be impacted by CDA (table 3 through table 18).
- New TSMO strategies not currently in the marketplace that are likely to be made possible by CDA (table 19).
- TSMO strategies currently in the marketplace that are not expected to be impacted by CDA (table 20).

Each TSMO strategy in table 3 through table 19 is profiled in terms of identifier, description, and Cooperation Classes applicable to the strategy. Table 3 through table 18 also identify the additional benefits of CDA on the subject strategy. Table 20 only shows the group and description of each TSMO strategy because these strategies are not expected to be impacted by CDA.

Each TSMO strategy and Cooperation Class association in table 3 through table 19 constitutes a unique use case. The use cases, once defined, highlight the impacts of CDA Automation Levels and Cooperation Classes on the TSMO strategies. Four use cases—basic travel, TIM, RWM, and WZM—are detailed in table 38 through table 41.

Table 3 through table 19 present the key TSMO strategies and their relationships to CDA.

Arterial management, as seen in table 3, is the management of arterial facilities in a manner that provides users with a safe, efficient, and reliable trip.

Table 3. Arterial management and relationship to CDA.

Identifier	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 driveway spacing, safe turning lanes, median treatments, and so on.	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 signal timing is a concept where 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 strategy: Signal Timing for Bicycles and Pedestrians (1-4)	Signal retiming/optimization is a concept to optimize traffic flow.	A, B	Improved historical traffic data for non-real-time adjustments. Reduced reliance on physical sensor devices and maintenance.
1-4	**Signal Timing for Bicycles and Pedestrians** Related strategy: Signal Retiming/Optimization (1-3)	Signal timing for bicycles and pedestrians is an operational strategy for reducing the delay pedestrians 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.
1-5	**Transit Signal Priority** Related strategy: Adaptive Signal Timing (1-2)	Transit signal priority 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 strategy: Adaptive Signal Timing (1-2)	Truck traffic signal priority is an operational strategy for reducing the delay commercial vehicles experience at traffic signals	A, B, C	Improved freight vehicle detection. Enhanced real-time traffic detection algorithms for priority.

Active traffic management (ATM), presented in table 4, is 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 4. ATM and relationship to CDA.

Identifier	TSMO Strategies	Description	Cooperation Class	Additional Benefit to Existing TSMO Strategy
2-1	**Dynamic Junction Control** Related strategies: none	Dynamic junction control consists of dynamically allocating lane access on mainline and ramp lanes in interchange areas where 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** Related strategies: none	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 employs special overhead signals that permit or prohibit the use of specific lanes of a street or highway or 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 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 stoppage or slowdown of traffic.	A, B	Improved queue detection and location accuracy. Enhanced safety, particularly for Class B vehicles.
2-5	**Reversible Lanes** Related strategies: none	Reversible lanes is an operational strategy where the direction of traffic flow on a roadway is reversed depending on traffic demand.	A, B, C	Improved reversal times based on additional traffic data. Improved conflict detection. Improved warning systems.

Identifier	TSMO Strategies	Description	Cooperation Class	Additional Benefit to Existing TSMO Strategy
2-6	**Ramp Metering** Related strategies: none	Ramp metering uses traffic signals installed on freeway onramps to control the frequency at which vehicles enter the flow of traffic. Ramp metering reduces overall freeway congestion by managing the volume of traffic entering the freeway and 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 Cass 2 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 where 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 Variable Speed Limit Application (8-10)	Speed harmonization, often referred to as variable speed limits, is a strategy for managing traffic flow and congestion whereby speed limits are adjusted based on traffic and weather conditions.	A, B	Improved speed harmonization due to high-frequency data. Enhanced safety, particularly for Class B vehicles.
2-9	**Shoulder Lanes** Related strategies: Traffic-Incident Management (11-2), Work-Zone Management (15-1), Special Event Management (10-1)	Shoulder lanes enable 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. Improved high-frequency data to optimize when to implement hard shoulder running. Enhanced safety.

Congestion pricing (table 5) encompasses roadway pricing that varies by time of day based on the level of congestion on the facility.

Table 5. Congestion pricing and relationship to CDA.

Identifier	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)	Areawide charging involves per-unit charges within a given geographical area, 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)	Cordon charging is a strategy that 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)	Electric toll collection uses electronic methods of 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)	Variable tolls change 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.

Emergency transportation operations (table 6) provide users with a safe and efficient transportation system during emergency situations.

Table 6. Emergency transportation operations and relationship to CDA.

Identifier	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 predefined procedures to assist in a safe and efficient evacuation.	A, B, C	Improved evacuation strategy based on vehicle data. Improved safety, particularly for Class B vehicles.
4-2	**Emergency Preparedness** Related strategies: Evacuation Management (4-1), Emergency Response (4-3), Decision Support System (6-1)	Emergency preparedness 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 by using 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 Prearrival Staging Guidance for Emergency Responders (RESP-STG) (16-4), Emergency Path Clearance (17-11), Safety Buffer (17-18), Lane Clear (17-13)	Emergency response involves the TMS operational response to emergency incidents and disasters.	A, B, C	Improved safety from additional traffic data. Improved safety, particularly for Class B vehicles. Optimized emergency routing.

ICM = integrated corridor management.

Freight technology and operations (table 7) deal with 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. Goal achievement may range from satisfying customers (e.g., freight shippers, receivers, and carriers) to actual travel time on the system.

Table 7. Freight technology and operations and relationship to CDA.

Identifier	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)	Fleet management involves location tracking and route planning for commercial vehicles and those owned by DOTs.	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)	Commercial motor vehicle electronic screening/clearance is a strategy to screen/clear freight vehicles using various criteria, including size and weight restrictions.	A, B	Automatic electronic screening and clearance of vehicle attributes. Reduced travel time. Ability to charge fees based on O-D and vehicle attributes.

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

Integrated corridor management (ICM) (table 8) is 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 to make more educated travel decisions through better information and more choices.

Table 8. ICM and relationship to CDA.

Identifier	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 Integrated Corridor Management** Related strategies: all	Freeway/arterial ICM involves the combined application of technologies and integration of various TSMO strategies and network partners, all collaborating to optimize traffic flow in a corridor.	A, B, C	Improved alternate routes. Benefits to load balancing. Improved safety through additional data inputs.

Managed lanes (table 9) are highway facilities or lanes where operational strategies are proactively implemented and managed in response to changing conditions.

Table 9. Managed lanes and relationship to CDA.

Identifier	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)	High-occupancy toll lanes is a strategy involving any high-occupancy vehicle lane that allows vehicles not meeting minimum occupancy requirements to use the lane by paying a toll.	A, B	Optimized high-occupancy toll activation based on additional high-frequency traffic data. More granular toll rates. Tolls based on vehicle attributes and number of occupants.
7-2	**High-Occupancy Vehicle Lanes** Related strategies: none	High-occupancy vehicle lanes is a strategy involving 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, other highway or street, or independent roadway on a separate right-of-way.	A	Number-of-occupants detection. Improved high-occupancy vehicle 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)	Lanes dedicated as transit or commercial motor vehicles only 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.

RWM (table 10) focuses on providing users with a safe and efficient transportation system during and after weather events.

Table 10. RWM and relationship to CDA.

Identifier	TSMO Strategies	Description	Cooperation Class	Additional Benefit to Existing TSMO Strategy
8-1	**En Route Weather Alerts and Pavement Condition Information** Related strategy: 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 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)	Motorist advisory and warning systems collect 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 strategy: Predictive Traveler Information (12-3)	Pretrip condition information and forecast systems involve the use of 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 Class B vehicles.
8-4	**Route Optimization for Snowplows** Related strategy: Fleet Management (5-1)	Route optimization for snowplows involves dynamic optimization 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)	Winter operations include a number of activities that an organization undergoes to prepare for or address adverse winter conditions, such as salting the roadway and snow removal.	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)	Weather-related road restrictions limit access to roadways based on weather conditions.	A, B	Personalized warnings based on vehicle type and route for Class B vehicles. Faster identification of roadways that should be restricted based on weather conditions.

Identifier	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)	Weather-responsive traffic signal control adjusts signal controls based on current weather conditions.	A, B	Automatic adjustment based on more accurate location-based weather data. Ability to take vehicle attributes into account.
8-8	**Weather-Related Vehicle Restrictions** Related strategies: Roadside Truck Electronic Screening/Clearance (5-2), Digital Infrastructure Messaging (17-8)	Weather-related vehicle restrictions use 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 (2-8)	Weather speed advisories are used as a safety precaution 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 Cass 2 vehicles.
8-10	**Weather-Responsive Variable Speed Limit Application** Related strategy: Speed Harmonization (2-8)	Weather-responsive variable speed limit application consists of multiple roadside monitoring and display trailers with the ability to detect weather and traffic data.	A, B	Speed harmonization during adverse road weather events to streamline traffic and improve safety.

Safety management (table 11) presents safety policy measures.

Table 11. Safety management and relationship to CDA.

Identifier	TSMO Strategies	Description	Cooperation Class	Additional Benefit to Existing TSMO Strategy
9-1	**Bicycle Detection/Warning** Related strategy: Intersection Warnings (9-3)	Bicycle detection/warning 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**	Geometry warnings include 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)	Intersection warnings involve warning systems at intersections to provide supplemental safety-related information, such as traffic light status.	A, B	Benefit from being able to provide fast notifications to each vehicle depending on location and vehicle attributes.
9-4	**Pedestrian Detection/Warning** Related strategy: Intersection Warnings (9-3)	Pedestrian detection/warning includes a detection and warning system to alert drivers to pedestrians crossing the roadway.	A, B	Improved pedestrian detection. Targeted warnings.

Special event management (table 12) consists of planned special events (e.g., sporting events, concerts, festivals, and conventions) occurring at permanent multiuse venues (e.g., arenas, stadiums, racetracks, fairgrounds, amphitheaters, and convention centers).

Table 12. Special event management and relationship to CDA.

Identifier	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)	Special event management 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 Class B vehicles.

TIM, presented in table 13, consists of a planned and coordinated multidisciplinary process to detect, respond to, and clear traffic incidents so traffic flow can be restored as safely and quickly as possible.

Table 13. TIM and relationship to CDA.

Identifier	TSMO Strategies	Description	Cooperation Class	Additional Benefit to Existing TSMO Strategy
11-1	**Full-Function Service Patrols** Related strategy: Fleet Management (5-1)	Full-function service patrols are usually operated directly by or under contract to a State DOT. As such, the patrol can be the on-scene "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 Integration with Traffic Management Center 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 Integrated Corridor Management (6-2)	TIM consists of a planned and coordinated multidisciplinary process to detect, respond to, and clear traffic incidents so traffic flow can 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 Class B cooperation. Improved safety and mobility. Increased productivity.

DOT = department of transportation; TMC = traffic management center.

Traveler information (table 14) is designed to provide transportation system users with the information they need to choose the safest and most efficient mode and route of travel.

Table 14. Traveler information and relationship to CDA.

Identifier	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)	Multimodal regional traveler information 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	Parking availability information and guidance 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)	Predictive traveler information uses historical and real-time data to predict and notify the driver about 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.

Travel demand management (table 15) provides users with effective travel choices to shift or reduce the demand for travel under congested conditions.

Table 15. Travel demand management and relationship to CDA.

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

O-D = origin–destination.

Transit operations and management (table 16) encompasses the operation and management of the transit system in a safe and efficient manner.

Table 16. Transit operations and management and relationship to CDA.

Identifier	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)	Advanced transit operations involve 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)	High-performance transit 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.

WZM (table 17) 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 17. WZM and relationship to CDA.

Identifier	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)	WZM 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 safety for workers. Personalized warnings based on vehicle attributes. Improved work zone vehicle guidance.

Other TSMO strategies are presented in table 18.

Table 18. Other TSMO strategies and relationship to CDA.

Identifier	TSMO Strategies	Description	Cooperation Class	Additional Benefit to Existing TSMO Strategy
16-1	**Asset Management** Related strategies: Freeway/Arterial Integrated Corridor Management (6-2), Traffic-Incident Management (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	Bottleneck mitigation 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 using cooperative vehicle data.	A, B, C	Improved bottleneck alleviation.
16-3	**Data Marts and Data Warehouses** Related strategies: all	Data marts and data warehouses is a strategy that designs and builds a data warehouse to collect data that can be used by most other TSMO strategies.	A, B	Improved strategies by using higher 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)	Incident scene prearrival staging guidance for emergency responders (RESP-STG) involves guidance from the TMS regarding coordination at the incident scene through use of connected vehicle data.	A, B	Improved emergency response. Increased safety.
16-5	**Red-Light Violation Warning** Related strategy: Intersection Warnings (9-3)	Red-light violation warning provides advanced warning to vehicles based on their speed as they approach intersections with a traffic signal status of red.	A, B	Increased safety.

Potential new TSMO strategies are presented in table 19.

Table 19. Potential new TSMO strategies and relationship to CDA.

Identifier	TSMO Strategies	Description	Cooperation Class
17-1	**Automated Maintenance and Fleet-Management Systems** Related strategy: Fleet Management (5-1)	Automated maintenance and fleet management systems automate 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)	Automated maintenance decision support system 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)	Break long queues on arterials supports allowing side-street vehicle crossing/merging.	B, C
17-4	**Cooperative Lane-Balancing** Related strategies: none	Cooperative lane-balancing uses the interaction between TMSs and CDA to lane-balance 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)	Cooperative weather-responsive conflict management 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)	Curbside management optimizes curb demand to provide reliable access.	B, C
17-7	**Dedicated Automated Driving System Lanes** Related strategies: none	Dedicated automated driving system lanes dedicates a lane to ADS to encourage and optimize the benefits to support freeway capacity.	A, B, C
17-8	**Digital Infrastructure Messaging** Related strategies: all	Digital infrastructure messaging 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)	Disabled vehicle beacon uses cooperative communication to broadcast information regarding a disabled vehicle to approaching CDA vehicles.	A
17-10	**Dynamic Route Guidance** Related strategy: Traffic-Incident Management (11-2)	Dynamic route guidance augments a user's navigation with real-time traffic, transit, and road condition information from a TMS or third-party to assist with route guidance. Dynamic route guidance may also include instructions and guidance to balance traffic flows (dynamic traffic assignment).	B

Identifier	TSMO Strategies	Description	Cooperation Class
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)	Emergency path clearance 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)	Intersection conflict management uses cooperative vehicle data to give advanced warning of potential collisions at intersections. Intersection conflict management 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)	Lane clear 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)	Lateral vehicle formations coordinate the operation of vehicles traveling side-by-side in adjacent lanes (i.e., lateral platooning).	B, C
17-15	**Perceived Lane Capacity** Related strategies: none	Perceived lane capacity provides lane-level speed and occupancy data from perception sensors shared from CDA vehicles.	A, B
17-16	**Railroad-Crossing Conflict Management** Related strategies: none	Railroad-crossing conflict management uses CDA to coordinate potential railroad-crossing conflicts.	B
17-17	**Safe Stop** Related strategies: none	Safe stop involves law enforcement in safely stopping an ADS or CDA vehicle.	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)	Safety buffer uses cooperative communications to broadcast a safety zone geofence around first responders to enforce Move Over laws.	B, C
17-19	**Vehicle Platooning** Related strategies: none	Vehicle platooning coordinates the operation of vehicles traveling closely behind each other at high speeds.	B, C

Nonimpacted TSMO strategies are presented in table 20.

Table 20. TSMO strategies not expected to be impacted by CDA.

Identifier	TSMO Strategies	Description
18-1	**Computer-Aided Dispatch Integration with Traffic Management Center Operations** Related strategies: Traffic-Incident Management (11-2), Emergency Response (4-3)	Computer-aided dispatch integration with traffic management center operations integrates data between TMSs and computer-aided dispatch databases; it helps incident responders to collaborate, reducing response time and aiding in incident management.
18-2	**Quick-Clearance Policies** Related strategy: Traffic-Incident Management (11-2)	Quick-clearance policies provide 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)	Wrecker response contracts pertain to contracts with towing companies for removing 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)	Mass media communication involves traditional advertising methods, such as radio/television or Internet, to reach drivers with safety warnings.
18-5	**Traveler Information Marketing Campaigns** Related strategies: none	Traveler information marketing campaigns publish and market traveler information through a variety of means, including print, Internet, and other media outlets, to make sure travelers are aware of available options.
18-6	**Employer Programs** Related strategies: none	Employer programs involve employers assisting their staff with subsidized travel options to encourage the use of public transport, carpools, and so on.
18-7	**Telecommuting** Related strategies: none	Telecommuting involves individuals working remotely.
18-8	**Urban Centers, Corridor, and Industrial Area Investments** Related strategies: none	Urban centers, corridor, and industrial area investments involve 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 (8-1)	Agency coordination and integration involves communications between departments to optimize relevant regional strategies.
18-10	**Unmanned Aerial Systems Detection and Monitoring** Related strategies: none	Unmanned aerial systems detection and monitoring uses tethered drones and relay drones to detect and monitor incidents.

TSMO STRATEGIES AND CANDIDATE CDA DATA TYPES

Table 21 identifies the essential data elements needed to implement the corresponding TSMO strategies. The data types are defined as follows:

- Speed—the velocity of an individual vehicle at a given point.
- Heading—the direction of travel of the vehicle at a given point.
- Vehicle location—the latitude and longitude of the vehicle.

- Origin–destination (O-D)—the start and intended end location of the entire trip for a particular vehicle. O-D data cannot be derived from vehicle location data because vehicle location data cannot be provided with a unique and traceable vehicle identifier through a transportation network. O-D data can be provided from fleet vehicles with professional drivers. This is to protect the privacy of citizens.
- Braking—the deceleration status of a vehicle. These data may include activation of antilock, systems traction, and stability control.
- Vehicle attributes—available characteristics of a specified vehicle. Vehicle attributes include type, height, width, weight, emissions, and so on.
- Road weather data—available vehicle data regarding real-time weather conditions, such as windshield wiper status, rain sensors, ambient air temperature, pressure readers, and so on. Road weather data can be used to inform other vehicles of downstream weather-related hazards and enhance weather predictions. Road weather data can also include more detailed road-surface data obtained from maintenance vehicles with mobile weather-detection equipment. In addition to the aforementioned passenger-vehicle data, the data from maintenance vehicles may include road surface status (e.g., wet, freezing, dry), road surface temperature, and so on.
- Number of occupants—the number of detected individuals in a vehicle at the time the data were sent. If the data are not available, it is assumed that the vehicle will not send any occupancy information and statistical information about vehicle occupancy might be used.
- Crash—information about a crash, including location (e.g., mile marker and direction of travel); type of vehicle; hazardous material information, if applicable; and severity.
- Lane closures—number and location of lanes closed due to incidents (e.g., work zones, special events).

As shown in figure 3 and figure 4, a data analytics platform, such as a vehicle-to-everything (V2X) module that could be standalone or integrated with an active traffic management system (ATMS), can filter raw datasets and capture the elements of interest. The data can then be reported at the needed frequencies of a frontend graphical user interface in the TMS or integrated with the ATMS software modules used to control the TSMO strategy implementation. The CARMA Cloud development may need to consider integration with a V2X module.

Table 21 through table 37 present several TSMO strategies and essential CDA data elements.

Arterial management, as seen in table 21, is the management of arterial facilities in a manner that provides users with a safe, efficient, and reliable trip.

Table 21. Arterial management and essential CDA data elements.

Identifier	TSMO Strategies	Speed, Heading, Vehicle Location	O-D	Braking	Vehicle Attributes	Road Weather Data	Number of Vehicle Occupants	Crash	Lane Closure (e.g., Incident, Work Zone)
1-1	**Access Management**	X	X	—	—	—	—	X	X
1-2	**Adaptive Signal Timing**	X	X	—	X	—	—	X	—
1-3	**Signal Retiming/ Optimization**	X	—	—	—	—	—	X	—
1-4	**Signal Timing for Bicycles and Pedestrians**	X	—	—	—	—	—	—	—
1-5	**Transit Signal Priority**	X	X	—	X	—	X	—	—
1-6	**Truck Traffic Signal Priority**	X	X	—	X	—	—	—	—

—No data.
X Essential data elements.

ATM, as seen in table 22, is 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 22. ATM and essential CDA data elements.

Identifier	TSMO Strategies	Speed, Heading, Vehicle Location	O-D	Braking	Vehicle Attributes	Road Weather Data	Number of Vehicle Occupants	Crash	Lane Closure (e.g., Incident, Work Zone)
2-1	**Dynamic Junction Control**	X	—	X	X	—	X	X	X
2-2	**Dynamic Merge Control**	X	—	X	—	—	—	—	X
2-3	**Lane-Use Control**	X	—	—	—	—	—	X	X
2-4	**Queue Warning**	X	—	X	—	—	—	X	X
2-5	**Reversible Lanes**	X	X	—	—	—	—	X	X
2-6	**Ramp Metering**	X	—	X	—	—	—	X	X
2-7	**Real-Time Traffic Monitoring**	X	X	—	X	—	—	X	X
2-8	**Speed Harmonization**	X	—	X	—	—	—	—	—
2-9	**Shoulder Lanes**	X	—	—	—	—	—	X	X

—No data.
X Essential data elements.

Congestion pricing, as seen in table 23, encompasses roadway pricing that varies by time of day based on the level of congestion on the facility.

Table 23. Congestion pricing and essential CDA data elements.

Identifier	TSMO Strategies	Speed, Heading, Vehicle Location	O-D	Braking	Vehicle Attributes	Road Weather Data	Number of Vehicle Occupants	Crash	Lane Closure (e.g., Incident, Work Zone)
3-1	**Areawide Charging**	X	—	—	X	—	—	—	X
3-2	**Cordon Charging**	X	—	—	X	—	—	—	X
3-3	**Electronic Toll Collection**	X	—	—	X	—	—	—	X
3-4	**Variable Tolls**	X	X	—	X	—	X	—	—

—No data.
X Essential data elements.

Emergency transportation operations, as seen in table 24, provide users with a safe and efficient transportation system during emergency situations.

Table 24. Emergency transportation operations and essential CDA data elements.

Identifier	TSMO Strategies	Speed, Heading, Vehicle Location	O-D	Braking	Vehicle Attributes	Road Weather Data	Number of Vehicle Occupants	Crash	Lane Closure (e.g., Incident, Work Zone)
4-1	**Evacuation Management**	X	X	—	X	X	X	X	—
4-2	**Emergency Preparedness**	X	X	—	—	—	—	X	X
4-3	**Emergency Response**	X	—	—	X	X	X	X	—

—No data.
X Essential data elements.

Freight technology and operations, as seen in table 25, deal with 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. Goal achievement may range from satisfying the customer (e.g., freight shippers, receivers, and carriers) to actual travel time on the system.

Table 25. Freight technology and operations and essential CDA data elements.

Identifier	TSMO Strategies	Speed, Heading, Vehicle Location	O-D	Braking	Vehicle Attributes	Road Weather Data	Number of Vehicle Occupants	Crash	Lane Closure (e.g., Incident, Work Zone)
5-1	**Fleet Management**	X	X	—	X	X	X	X	X
5-2	**Roadside Truck Electronic Screening/ Clearance**	X	X	—	X	—	—	—	—

—No data.
X Essential data elements.

ICM, as seen in table 26, is 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, such as State and local, and transit agencies, manage the corridor as an integrated asset to improve travel time reliability and predictability, help manage congestion, and empower travelers to make more educated travel decisions through better information and more choices.

Table 26. ICM and essential CDA data elements.

Identifier	TSMO Strategies	Speed, Heading, Vehicle Location	O-D	Braking	Vehicle Attributes	Road Weather Data	Number of Vehicle Occupants	Crash	Lane Closure (e.g., Incident, Work Zone)
6-1	**Decision Support System**	X	X	X	X	X	X	X	X
6-2	**Freeway/ Arterial ICM**	X	X	X	X	X	X	X	X

X Essential data elements.

Managed lanes, as seen in table 27, are highway facilities or lanes where operational strategies are proactively implemented and managed in response to changing conditions.

Table 27. Managed lanes and essential CDA data elements.

Identifier	TSMO Strategies	Speed, Heading, Vehicle Location	O-D	Braking	Vehicle Attributes	Road Weather Data	Number of Vehicle Occupants	Crash	Lane Closure (e.g., Incident, Work Zone)
7-1	**High-Occupancy Toll Lanes**	X	—	—	—	—	X	X	X
7-2	**High-Occupancy Vehicle Lanes**	X	—	—	—	—	X	X	X
7-3	**Lanes Dedicated as Transit or Trucks Only**	X	X	—	X	—	X	X	X

—No data.
X Essential data elements.

RWM, as seen in table 28, focuses on providing users with a safe and efficient transportation system during and after weather events.

Table 28. RWM and essential CDA data elements.

Identifier	TSMO Strategies	Speed, Heading, Vehicle Location	O-D	Braking	Vehicle Attributes	Road Weather Data	Number of Vehicle Occupants	Crash	Lane Closure (e.g., Incident, Work Zone)
8-1	**En Route Weather Alerts and Pavement Condition Information**	X	X	X	X	X	—	X	X
8-2	**Motorist Advisory and Warning Systems**	X	X	X	X	X	—	X	X

Identifier	TSMO Strategies	Speed, Heading, Vehicle Location	O-D	Braking	Vehicle Attributes	Road Weather Data	Number of Vehicle Occupants	Crash	Lane Closure (e.g., Incident, Work Zone)
8-3	**Pretrip Condition Information and Forecast Systems**	X	X	X	X	X	—	X	X
8-4	**Route Optimization for Snowplows**	X	X	—	X	X	—	X	X
8-5	**Winter Operations**	X	—	X	X	X	—	X	X
8-6	**Weather-Related Road Restrictions**	X	X	X	X	X	—	X	X
8-7	**Weather-Responsive Traffic Signal Control**	X	X	X	X	X	—	X	X
8-8	**Weather-Related Vehicle Restrictions**	X	X	—	X	X	—	X	X
8-9	**Weather Speed Advisories**	X	—	X	X	X	—	X	X
8-10	**Weather-Responsive Variable Speed Limit Application**	X	—	X	X	X	—	X	X

—No data.
X Essential data elements.

Safety management, as seen in table 29, addresses safety policy measures.

Table 29. Safety management and essential CDA data elements.

Identifier	TSMO Strategies	Speed, Heading, Vehicle Location	O-D	Braking	Vehicle Attributes	Road Weather Data	Number of Vehicle Occupants	Crash	Lane Closure (e.g., Incident, Work Zone)
9-1	**Bicycle Detection/ Warning**	X	—	X	X	—	—	X	—
9-2	**Geometry Warnings**	X	—	X	X	—	—	X	X
9-3	**Intersection Warnings**	X	—	X	X	—	—	X	—
9-4	**Pedestrian Detection/ Warning**	X	—	X	X	—	—	X	—

—No data.
X Essential data elements.

Special event management, as seen in table 30, encompasses planned special events (e.g., sporting events, concerts, festivals, and conventions) occurring at permanent multiuse venues (e.g., arenas, stadiums, racetracks, fairgrounds, amphitheaters, and convention centers).

Table 30. Special event management and essential CDA data elements.

Identifier	TSMO Strategies	Speed, Heading, Vehicle Location	O-D	Braking	Vehicle Attributes	Road Weather Data	Number of Vehicle Occupants	Crash	Lane Closure (e.g., Incident, Work Zone)
10-1	**Special Event Management**	X	X	—	X	X	X	X	X

—No data.
X Essential data elements.

TIM, as seen in table 31, consists of a planned and coordinated multidisciplinary process to detect, respond to, and clear traffic incidents so traffic flow can be restored as safely and quickly as possible.

Table 31. TIM and essential CDA data elements.

Identifier	TSMO Strategies	Speed, Heading, Vehicle Location	O-D	Braking	Vehicle Attributes	Road Weather Data	Number of Vehicle Occupants	Crash	Lane Closure (e.g., Incident, Work Zone)
11-1	**Full-Function Service Patrols**	X	X	—	X	X	—	X	—
11-2	**Traffic-Incident Management**	X	X	X	X	X	X	X	X

—No data.
X Essential data elements.

Traveler information, as seen in table 32, is designed to provide transportation system users with the information they need to choose the safest and most efficient mode and route of travel.

Table 32. Traveler information and essential CDA data elements.

Identifier	TSMO Strategies	Speed, Heading, Vehicle Location	O-D	Braking	Vehicle Attributes	Road Weather Data	Number of Vehicle Occupants	Crash	Lane Closure (e.g., Incident, Work Zone)
12-1	**Multimodal Regional Traveler Information**	X	X	—	X	—	X	X	X
12-2	**Parking Availability Information and Guidance**	X	X	—	X	—	—	—	—
12-3	**Predictive Traveler Information**	X	X	X	X	X	X	X	X
12-4	**Real-Time Transit Arrival Information**	X	X	—	X	—	—	X	X

—No data.
X Essential data elements.

Travel demand management, as seen in table 33, is defined as providing users with effective travel choices to shift or reduce the demand for travel in congested conditions.

Table 33. Travel demand management and essential CDA data elements.

Identifier	TSMO Strategies	Speed, Heading, Vehicle Location	O-D	Braking	Vehicle Attributes	Road Weather Data	Number of Vehicle Occupants	Crash	Lane Closure (e.g., Incident, Work Zone)
13-1	**Commuter Incentives**	X	X	—	X	—	—	—	—
13-2	**First/ Last-Mile Connectivity**	X	X	—	X	—	X	—	—
13-3	**Rideshare System**	X	X	—	X	—	X	—	—

—No data.
X Essential data elements.

Transit operations and management, as seen in table 34, encompasses the operation and management of the transit system in a safe and efficient manner.

Table 34. Transit operations and management and essential CDA data elements.

Identifier	TSMO Strategies	Speed, Heading, Vehicle Location	O-D	Braking	Vehicle Attributes	Road Weather Data	Number of Vehicle Occupants	Crash	Lane Closure (e.g., Incident, Work Zone)
14-1	**Advanced Transit Operations**	X	X	X	X	X	X	X	X
14-2	**High-Performance Transit**	X	X	X	X	—	X	X	X

—No data.
X Essential data elements.

WZM, as seen in table 35, involves organizing and operating areas impacted by road or rail construction to minimize traffic delays, maintain safety for workers and travelers, and accomplish the work efficiently.

Table 35. WZM and essential CDA data elements.

Identifier	TSMO Strategies	Speed, Heading, Vehicle Location	O-D	Braking	Vehicle Attributes	Road Weather Data	Number of Vehicle Occupants	Crash	Lane Closure (e.g., Incident, Work Zone)
15-1	**Work-Zone Management**	X	—	X	X	X	—	X	X

—No data.
X Essential data elements.

Other TSMO strategies are shown in table 36.

Table 36. Other TSMO strategies and essential CDA data elements.

Identifier	TSMO Strategies	Speed, Heading, Vehicle Location	O-D	Braking	Vehicle Attributes	Road Weather Data	Number of Vehicle Occupants	Crash	Lane Closure (e.g., Incident, Work Zone)
16-1	**Asset Management**	—	—	—	—	X	—	—	X
16-2	**Bottleneck Mitigation**	—	X	—	—	—	—	X	X
16-3	**Data Marts and Data Warehouses**	X	X	X	X	X	X	X	X
16-4	**Incident Scene Prearrival Staging Guidance for Emergency Responders (RESP-STG)**	X	X	X	X	X	X	X	X
16-5	**Red Light Violation Warning**	X	—	X	X	X	—	X	—

—No data.
X Essential data elements.

Potential new TSMO strategies made possible by CDA data are shown in table 37.

Table 37. Potential new TSMO strategies made possible by CDA data.

Identifier	TSMO Strategies	Speed, Heading, Vehicle Location	O-D	Braking	Vehicle Attributes	Road Weather Data	Number of Vehicle Occupants	Crash	Lane Closure (e.g., Incident, Work Zone)
17-1	**Automated Maintenance and Fleet-Management Systems**	X	X	X	X	X	—	—	—
17-2	**Automated Maintenance Decision Support System**	X	X	X	X	X	—	—	—
17-3	**Break Long Queues on Arterials**	X	X	X	X	—	—	—	—
17-4	**Cooperative Lane Balancing**	X	X	X	X	—	—	X	X
17-5	**Cooperative Weather-Responsive Conflict Management**	X	X	X	X	X	X	X	X
17-6	**Curbside Management**	X	X	—	X	—	—	X	X
17-7	**Dedicated Automated Driving System Lanes**	X	—	—	X	—	—	X	X
17-8	**Digital Infrastructure Messaging**	X	X	—	X	—	—	—	—

Identifier	TSMO Strategies	Speed, Heading, Vehicle Location	O-D	Braking	Vehicle Attributes	Road Weather Data	Number of Vehicle Occupants	Crash	Lane Closure (e.g., Incident, Work Zone)
17-9	**Disabled Vehicle Beacon**	X	—	—	X	—	—	X	—
17-10	**Dynamic Route Guidance**	X	X	—	X	X	—	X	X
17-11	**Emergency Path Clearance**	X	X	X	X	—	—	X	X
17-12	**Intersection Conflict Management**	X	—	X	X	X	—	X	—
17-13	**Lane Clear**	X	X	—	X	—	—	X	X
17-14	**Lateral Vehicle Formations**	X	X	X	X	X	—	X	X
17-15	**Perceived Lane Capacity**	X	—	—	—	—	X	—	X
17-16	**Railroad Crossing Conflict Management**	X	—	X	X	X	—	—	—
17-17	**Safe Stop**	X	—	—	X	—	—	—	—
17-18	**Safety Buffer**	X	—	X	X	—	—	—	X
17-19	**Vehicle Platooning**	X	X	X	X	X	—	X	X

—No data.
X Essential data elements.

CHAPTER 4. USE CASE FRAMEWORK

INTRODUCTION

The framework concept for TSMO/TMS operations in relation to CDA must account for the different classes of cooperation between CDA-equipped vehicles and nonequipped vehicles, roadside equipment, and TMSs. In general, the framework concept presented in this chapter considers Classes A, B, and C, as described in the Cooperation Classes section in chapter 2.

FRAMEWORK CONCEPT FOR TSMO/TMS OPERATIONS IN RELATIONSHIP TO CDA

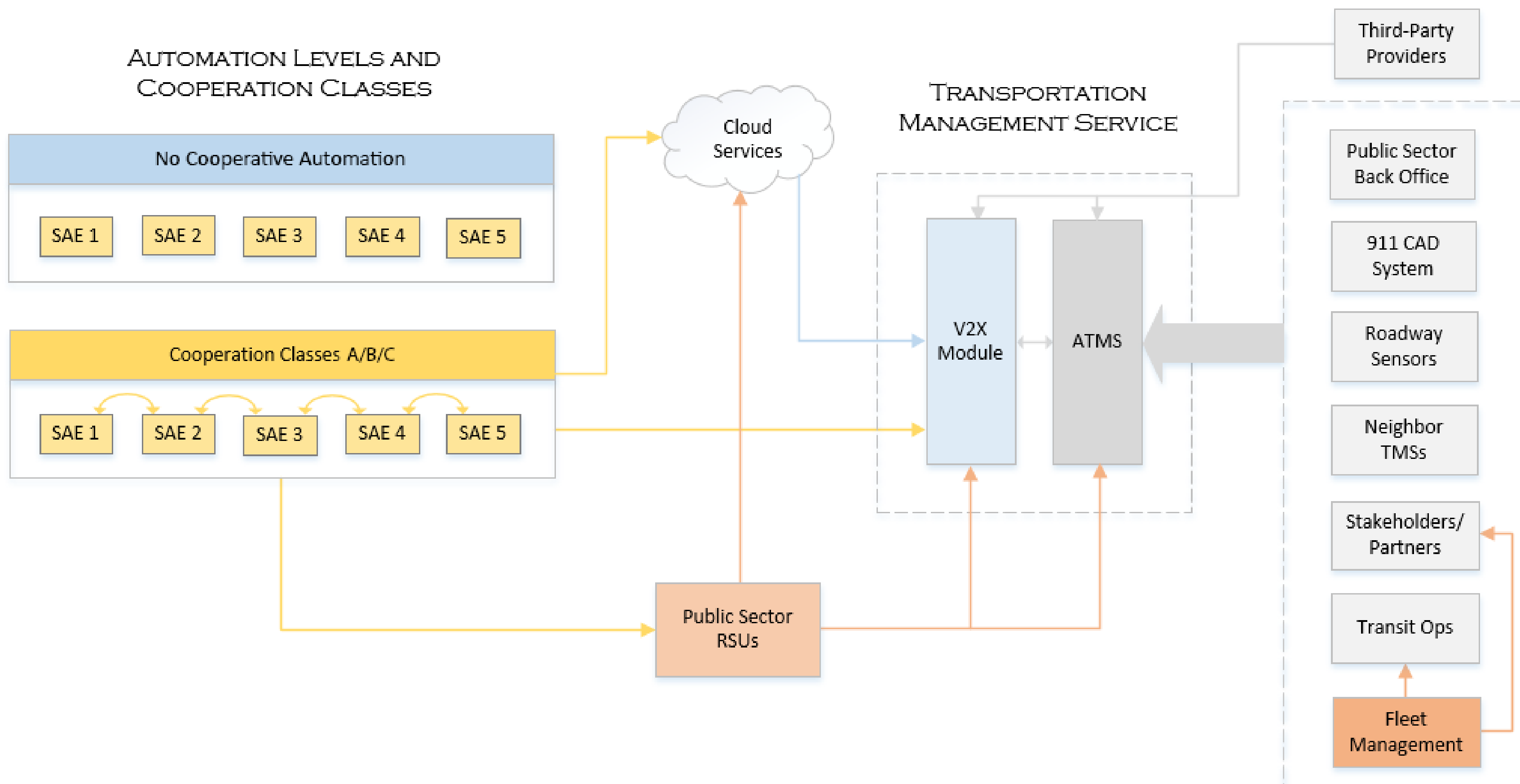
The framework design assumes that the data provided by a vehicle arrive at the TMS (and vice-versa), regardless of the underlying communications (i.e., short- or long-range) and whether there are intermediate devices (e.g., RSUs) relaying the data between TMSs and vehicles. The framework concept design also accounts for the Connected Vehicle Reference Information Architecture, particularly the Vehicle Data for Traffic Operations application.

The TMS entities in the framework concept include:

- Public-sector roadside equipment:
  - RSUs.
  - Intelligent transportation system infrastructure.
- Public-sector back-office systems:
  - Data distribution (e.g., operational data environment, CARMA Cloud).
  - Decision support (e.g., PikAlert).
  - Data archives (e.g., performance measurement systems).
  - Security.
- Third-party services:
  - Internet service providers.
  - OEM/ADS providers.

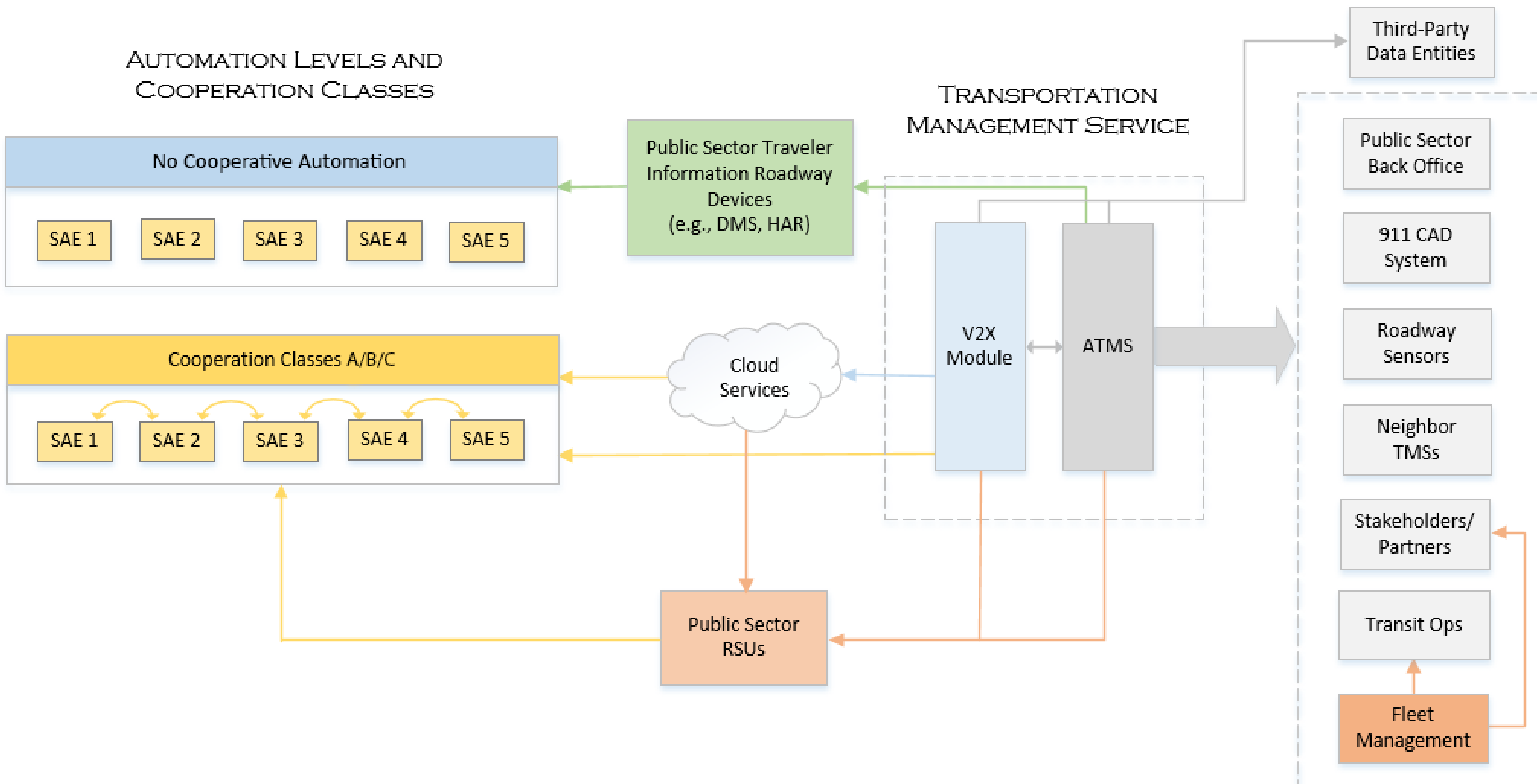
Figure 3 and figure 4 provide an overview of the interactions between TMSs and vehicles with different automation and cooperation capabilities, such as the following:

- Class A—handling current status information about the entities involved.
- Class B—sharing both current status and future intentions so the entities can work together.
- Class C—planning joint activities that can be performed in concert.



Source: FHWA.
CAD = computer-aided dispatch; Ops = operations.

Figure 3. Diagram. TMS inputs in a CDA environment.



Source: FHWA.
CAD = computer-aided dispatch; HAR = highway advisory radio; Ops = operations.

Figure 4. Diagram. TMS outputs in a CDA environment.

The columns of entities in figure 3 and figure 4 distinguish between the vehicles, the TSMO-executing TMS, field devices (both traditional and CDA-related, such as RSUs), and the third-party data entities that provide inputs and receive outputs based on the TSMO-related TMS–vehicle interactions. TMS refers to any entity that operates a transportation facility in a TSMO context and interacts with field equipment and vehicles either directly or via intermediate devices, such as RSUs.

Within this network, vehicles and TMS operations can interface in three ways: via short-range communications with RSUs, via cloud services, or directly with the TMS. The connected vehicle data-processing platform can be a standalone system integrated with the ATMS or a module within the ATMS software. The V2X module is shown in figure 3 and figure 4 apart from the ATMS. The V2X module can also interact directly with third-party data entities and receive relevant data from those third parties depending on the design of the overall system. Arrows show the direction the data flows. The arrow colors are only for clarification and are related to the originating entity.

Figure 3 shows the relevant TMS data-input sources used as the TMS executes the TSMO strategies, whereas figure 4 shows the entities receiving the data. In many use cases, these interactions will remain the same except for a few modifications. Table 38 through table 41 describe the interactions and modifications in detail.

Framework for Basic Travel Use Case

From a TMS operations perspective, table 38 shows the information a TMS can provide to CDA vehicles for basic travel vehicle operations, the information vehicles of different Automation Levels/Cooperation Classes can provide to a TMS to support the basic travel data needs, and the information vehicles with different Automation Levels/Cooperation Classes can provide between one another during basic travel. The TMS will continue furnishing relevant data to drivers as it does now.

For basic travel, the TSMO-focused TMS operations are defined by those recurring activities that TMSs, and especially traffic management centers (TMCs), routinely perform during normative operations when there are no incidents, events, or other anomalies. The operational action associated with basic travel is notify and advise, which is defined as providing situational awareness information to vehicles, regardless of Automation Level. Additional information, such as signal phasing and timing, geographic layouts of the roadways and intersections (map data), transit signal priority and emergency vehicle preemption requests and acknowledgments, and generic traveler information (e.g., TIM and TIM specific to CDA, and so on) can be provided by and for the vehicles.

All content in table 38 is in addition to data determined by onboard sensing equipment that enable vehicles to detect, process, and react to obstacles and other vehicles and pedestrians in their path.

Table 38. Framework for TSMO within a CDA environment—basic travel use case.

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Notify and advise	No cooperation automation	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.
Notify and advise	A	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast vehicle location, speed, and heading data (i.e., traffic-situation data and vehicle-situation data). 2. Broadcast vehicle data, such as traffic and environmental data (i.e., vehicle-situation data).(3) 3. Broadcast raw and/or processed vehicle speeds, counts, and other derived measures (i.e., traffic-situation data).(3)	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast vehicle location, speed, and heading data (i.e., traffic-situation data and vehicle-situation data). 2. Broadcast vehicle data, such as traffic and environmental data (i.e., vehicle-situation data).(3) 3. Broadcast raw and/or processed vehicle speeds, counts, and other derived measures (i.e., traffic-situation data).(3)	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast vehicle location, speed, and heading data (i.e., traffic-situation data and vehicle-situation data). 2. Broadcast vehicle data, such as traffic and environmental data (i.e., vehicle-situation data).(3) 3. Broadcast raw and/or processed vehicle speeds, counts, and other derived measures (i.e., traffic-situation data).(3)	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast vehicle location, speed, and heading data (i.e., traffic-situation data and vehicle-situation data). 2. Broadcast vehicle data, such as traffic and environmental data (i.e., vehicle-situation data).(3) 3. Broadcast raw and/or processed vehicle speeds, counts, and other derived measures (i.e., traffic-situation data).(3)	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast vehicle location, speed, and heading data (traffic-situation data and vehicle-situation data). 2. Broadcast vehicle data, such as traffic and environmental data (i.e., vehicle-situation data).(3) 3. Broadcast raw and/or processed vehicle speeds, counts, and other derived measures (i.e., traffic-situation data).(3)	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast vehicle location, speed, and heading data (traffic-situation data and vehicle-situation data). 2. Broadcast vehicle data, such as traffic and environmental data (i.e., vehicle-situation data).(3) 3. Broadcast raw and/or processed vehicle speeds, counts, and other derived measures (i.e., traffic-situation data).(3)
Notify and advise	A	TMS-to-vehicle data transfer includes the following: 1. Continuously broadcast data from signal controllers about their status. 2. Continuously broadcast data from field devices, such as curve warning systems, DMS messages, ramp meters, and so on. 3. Broadcast travel conditions data (i.e., road network conditions),(3) including allowed speed limits in geofenced areas. 4. Broadcast speed harmonization data.	TMS-to-vehicle data transfer includes the following in addition to Level 0: 1. Broadcast MAP data. 2. Broadcast data based on geofencing areas, including lane-level roadway conditions and real-time route guidance (e.g., direction).	TMS-to-vehicle data transfer includes the following in addition to Level 0: 1. Broadcast MAP data. 2. Broadcast data based on geofencing areas, including lane-level roadway conditions and real-time route guidance (e.g., direction).	TMS-to-vehicle data transfer includes the following in addition to Level 0: 1. Broadcast MAP data. 2. Broadcast data based on geofencing areas, including lane-level roadway conditions and real-time route guidance (e.g., direction).	TMS-to-vehicle data transfer includes the following in addition to Level 0: 1. Broadcast MAP data. 2. Broadcast data based on geofencing areas, including lane-level roadway conditions and real-time route guidance (e.g., direction).	TMS-to-vehicle data transfer includes the following in addition to Level 0: 1. Broadcast MAP data. 2. Broadcast data based on geofencing areas, including lane-level roadway conditions and real-time route guidance (e.g., direction).
Notify and advise	B	TMS-to-vehicle data transfer includes the following: In addition to Class A, transmit Signal Preemption/Priority Request acknowledgments and executions.	TMS-to-vehicle data transfer includes the following: In addition to Class A and Level 0, broadcast CDA rules for platooning (expected cooperative behavior).	TMS-to-vehicle data transfer includes the following: In addition to Class A and Level 0, broadcast CDA rules for platooning (expected cooperative behavior).	TMS-to-vehicle data transfer includes the following: In addition to Class A and Level 0, broadcast CDA rules for platooning (expected cooperative behavior).	TMS-to-vehicle data transfer includes the following: In addition to Class A and Level 0, broadcast CDA rules for platooning (expected cooperative behavior).	TMS-to-vehicle data transfer includes the following: In addition to Class A and Level 0, broadcast CDA rules for platooning (expected cooperative behavior).
Notify and advise	B	Vehicle-to-TMS data transfer includes the following: In addition to Class A, transmit Signal Preemption/Priority Requests.	Vehicle-to-TMS data transfer includes the following: Same as Class A and Level 0 for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A and Level 0 for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A and Level 0 for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A and Level 0 for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A and Level 0 for this operational action.

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Notify and advise	B	V2V data transfer includes the following: Merging onto streets or highways (covering right-turn-on-red operations and onramp merging), where each vehicle obtains status and intent data from surrounding vehicles and displays that to drivers to make their own decisions.	V2V data transfer includes the following: Same as Level 0 for this operational action.	V2V data transfer includes the following: Same as Level 0 for this operational action.	V2V data transfer includes the following: Merging onto streets or highways (covering right-turn-on-red operations and onramp merging), where each vehicle obtains status and intent data from surrounding vehicles and makes their decisions independently after taking account of the status and intent of other vehicles.	V2V data transfer includes the following: Same as Level 3 for this operational action.	V2V data transfer includes the following: Same as Level 3 for this operational action.
Notify and advise	C	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.
Notify and advise	C	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.
Notify and advise	C	V2V data transfer includes the following in addition to Class B: 1. Vehicle/truck platooning negotiations between platooning vehicles under consideration of local CDA rules for platooning (expected cooperative behavior). 2. Merging onto streets or highways (covering right-turn-on-red operations and onramp merging), with vehicles negotiating the operational behaviors of other involved vehicles.	V2V data transfer includes the following: Same as Level 0 for this operational action.	V2V data transfer includes the following: Same as Level 0 for this operational action.	Vehicle-to-vehicle data transfer includes the following: Same as Level 0 for this operational action.	V2V data transfer includes the following: Same as Level 0 for this operational action.	V2V data transfer includes the following: Same as Level 0 for this operational action.

MAP = map data.

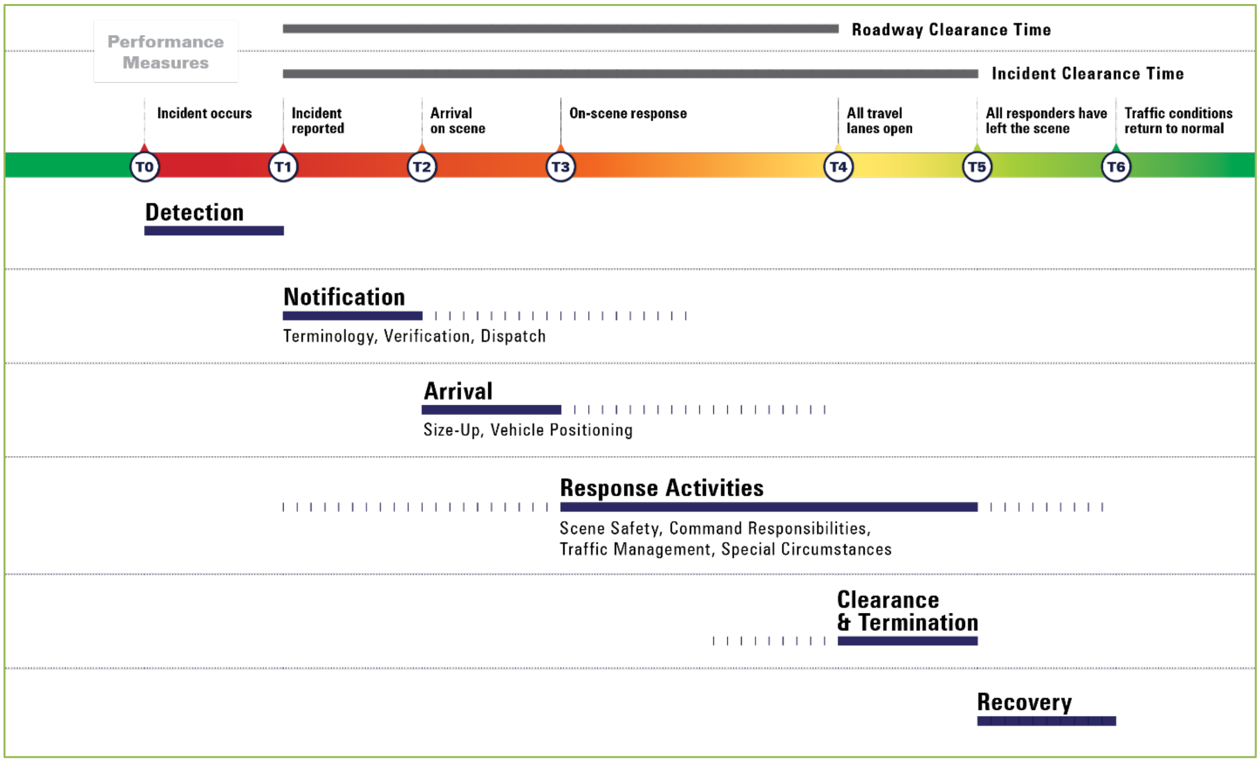
Framework for TIM Use Case

From a TMS operations perspective, table 39 shows the information a TMS can provide to CDA vehicles during incidents, the information vehicles of different Automation Levels/Cooperation Classes can provide to a TMS during incidents, and the information vehicles with different Automation Levels/Cooperation Classes can provide between one another during incidents. A TMS will continue furnishing relevant data to drivers as it does now.

For TIM, the TSMO-focused TMS operations are defined by those activities that TMSs, and especially TMCs, typically perform during incidents and other nonrecurring and unplanned anomalies. The operational actions associated with TIM are defined as follows:

- Detect—determining that an unusual situation occurred.
- Verify—ensuring the initial determination of an anomalous situation occurred.
- Notify and advise—informing first responders and motorists that an anomalous situation occurred, suggesting what drivers or vehicles might do to mitigate the circumstances, confirming what partnering agencies and third-party data users and providers should provide or receive, and so on. This also includes exchanging cooperative data between vehicles.
- Respond—performing activities in a structured manner to address and resolve the anomalous situation.
- Manage site—performing activities at and with the roadside to address and resolve the anomalous situation.
- Manage traffic—performing activities to manage traffic approaching and affected by the anomalous situation.
- Clear and terminate—performing activities to resolve the anomalous situation, including field device actions and informing other affected TMSs, motorists/vehicles, and the general public.
- Recover—performing activities to return the anomalous situation to normal operations after the affected roadway has been completely cleaned and all lanes are reopened to traffic.

Figure 5 depicts the steps and activities performed by TMS operators and incident management personnel during an incident, as defined in the *Traffic-Incident Management Handbook*.(1)



Source: FHWA.
T0 = incident detection time; T1 = incident notification time; T2 = responder arrival time; T3 = response activities time; T4 = incident clearance and termination time; T5 = recovery time; T6 = roadway returns to normal traffic conditions time.

Figure 5. Graph. TIM activities during an incident.

CDA-equipped vehicles encountering traffic incidents can exchange information about an incident detected by a vehicle and provide it to other CDA-equipped vehicles. V2V operations can exchange data much faster than a TMS and follow similar steps as exchanges between TMSs and vehicles.

All content in table 39 is in addition to data determined by onboard sensing equipment that enable vehicles to detect, process, and react to obstacles and other vehicles and pedestrians in their path.

Table 39. Framework for TSMO within a CDA environment—TIM use case.

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Detect	No cooperative automation	Operate as TMSs currently do, without automation and/or cooperation between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or cooperation between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or cooperation between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or cooperation between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or cooperation between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or cooperation between TMSs and vehicles.
Detect	A	TMS internal data transfer includes the following: 1. Various means to detect vehicles, such as loops, video, areal detection, or call-ins (911 or direct). 2. Incident data from third-party data providers. 3. Incident data from crowdsourcing providers. 4. Machine learning and AI tools to detect breakdowns.	TMS internal data transfer includes the following: 1. Various means to detect vehicles, such as loops, video, areal detection, or call-ins (911 or direct). 2. Incident data from third-party data providers. 3. Incident data from crowdsourcing providers. 4. Machine learning and AI tools to detect breakdowns.	TMS internal data transfer includes the following: 1. Various means to detect vehicles, such as loops, video, areal detection, or call-ins (911 or direct). 2. Incident data from third-party data providers. 3. Incident data from crowdsourcing providers. 4. Machine learning and AI tools to detect breakdowns.	TMS internal data transfer includes the following: 1. Various means to detect vehicles, such as loops, video, areal detection, or call-ins (911 or direct). 2. Incident data from third-party data providers. 3. Incident data from crowdsourcing providers. 4. Machine learning and AI tools to detect breakdowns.	TMS internal data transfer includes the following: 1. Various means to detect vehicles, such as loops, video, areal detection, or call-ins (911 or direct). 2. Incident data from third-party data providers. 3. Incident data from crowdsourcing providers. 4. Machine learning and AI tools to detect breakdowns.	TMS internal data transfer includes the following: 1. Various means to detect vehicles, such as loops, video, areal detection, or call-ins (911 or direct). 2. Incident data from third-party data providers. 3. Incident data from crowdsourcing providers. 4. Machine learning and AI tools to detect breakdowns.
Detect	A	Vehicle-to-TMS data transfer includes the following: 1. Detection of hard braking, sudden heading changes, ABS activation, or abnormal change in vehicle speeds (traffic-situation data and vehicle-situation data). 2. Broadcast crash, disabled vehicle, debris, police activity notification data (emergency notification), and HAZMAT information.(4)	Vehicle-to-TMS data transfer includes the following: 1. Detection of hard braking, sudden heading changes, ABS activation, or abnormal change in vehicle speeds (traffic-situation data and vehicle-situation data). 2. Broadcast crash, disabled vehicle, debris, police activity notification data (emergency notification), and HAZMAT information.(4)	Vehicle-to-TMS data transfer includes the following: 1. Detection of hard braking, sudden heading changes, ABS activation, or abnormal change in vehicle speeds (traffic-situation data and vehicle-situation data). 2. Broadcast crash, disabled vehicle, debris, police activity notification data (emergency notification), and HAZMAT information.(4)	Vehicle-to-TMS data transfer includes the following: 1. Detection of hard braking, sudden heading changes, ABS activation, or abnormal change in vehicle speeds (traffic-situation data and vehicle-situation data). 2. Broadcast crash, disabled vehicle, debris, police activity notification data (emergency notification), and HAZMAT information.(4)	Vehicle-to-TMS data transfer includes the following: 1. Detection of hard braking, sudden heading changes, ABS activation, or abnormal change in vehicle speeds (traffic-situation data and vehicle-situation data). 2. Broadcast crash, disabled vehicle, debris, police activity notification data (emergency notification), and HAZMAT information.(4)	Vehicle-to-TMS data transfer includes the following: 1. Detection of hard braking, sudden heading changes, ABS activation, or abnormal change in vehicle speeds (traffic-situation data and vehicle-situation data). 2. Broadcast crash, disabled vehicle, debris, police activity notification data (emergency notification), and HAZMAT information.(4)
Detect	A	TMS-to-vehicle data transfer includes the following: 1. Set data to be reported by vehicle (situation data collection parameters, vehicle-situation data parameters). 2. Acknowledge crash notification (emergency acknowledge).(5)	TMS-to-vehicle data transfer includes the following: 1. Set data to be reported by vehicle (situation data collection parameters, vehicle-situation data parameters). 2. Acknowledge crash notification (emergency acknowledge).(5)	TMS-to-vehicle data transfer includes the following: 1. Set data to be reported by vehicle (situation data collection parameters, vehicle-situation data parameters). 2. Acknowledge crash notification (emergency acknowledge).(5)	TMS-to-vehicle data transfer includes the following: 1. Set data to be reported by vehicle (situation data collection parameters, vehicle-situation data parameters). 2. Acknowledge crash notification (emergency acknowledge).(5)	TMS-to-vehicle data transfer includes the following: 1. Set data to be reported by vehicle (situation data collection parameters, vehicle-situation data parameters). 2. Acknowledge crash notification (emergency acknowledge).(5)	TMS-to-vehicle data transfer includes the following: 1. Set data to be reported by vehicle (situation data collection parameters, vehicle-situation data parameters). 2. Acknowledge crash notification (emergency acknowledge).(5)

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Detect	A	V2V data transfer includes the following: 1. If a vehicle is involved in a crash, it broadcasts that fact as well as other vehicle-internal data pertaining to the crash (assuming suitable sensors are in the vehicle). 2. If a vehicle is within detection range of the incident but not involved, vehicle broadcasts data about the crash-involved vehicles from its sensor fusion, including location, size, orientation of the involved vehicles, and a picture of the scene, if available.	V2V data transfer includes the following: 1. If a vehicle is involved in a crash, it broadcasts that fact as well as other vehicle-internal data pertaining to the crash (assuming suitable sensors are in the vehicle). 2. If a vehicle is within detection range of the incident but not involved, vehicle broadcasts data about the crash-involved vehicles from its sensor fusion, including location, size, orientation of the involved vehicles, and a picture of the scene, if available.	V2V data transfer includes the following: 1. If a vehicle is involved in a crash, it broadcasts that fact as well as other vehicle-internal data pertaining to the crash (assuming suitable sensors are in the vehicle). 2. If a vehicle is within detection range of the incident but not involved, vehicle broadcasts data about the crash-involved vehicles from its sensor fusion, including location, size, orientation of the involved vehicles, and a picture of the scene, if available.	V2V data transfer includes the following: 1. If a vehicle is involved in a crash, it broadcasts that fact as well as other vehicle-internal data pertaining to the crash (assuming suitable sensors are in the vehicle). 2. If a vehicle is within detection range of the incident but not involved, vehicle broadcasts data about the crash-involved vehicles from its sensor fusion, including location, size, orientation of the involved vehicles, and a picture of the scene, if available.	V2V data transfer includes the following: 1. If a vehicle is involved in a crash, it broadcasts that fact as well as other vehicle-internal data pertaining to the crash (assuming suitable sensors are in the vehicle). 2. If a vehicle is within detection range of the incident but not involved, vehicle broadcasts data about the crash-involved vehicles from its sensor fusion, including location, size, orientation of the involved vehicles, and a picture of the scene, if available.	V2V data transfer includes the following: 1. If a vehicle is involved in a crash, it broadcasts that fact as well as other vehicle-internal data pertaining to the crash (assuming suitable sensors are in the vehicle). 2. If a vehicle is within detection range of the incident but not involved, vehicle broadcasts data about the crash-involved vehicles from its sensor fusion, including location, size, orientation of the involved vehicles, and a picture of the scene, if available.
Detect	B	TMS-to-vehicle data transfer includes the following: There is no additional detect activity for Class B vehicles.	TMS-to-vehicle data transfer includes the following: There is no additional detect activity for Class B vehicles.	TMS-to-vehicle data transfer includes the following: There is no additional detect activity for Class B vehicles.	TMS-to-vehicle data transfer includes the following: There is no additional detect activity for Class B vehicles.	TMS-to-vehicle data transfer includes the following: There is no additional detect activity for Class B vehicles.	TMS-to-vehicle data transfer includes the following: There is no additional detect activity for Class B vehicles.
Detect	B	Vehicle-to-TMS data transfer includes the following: There is no additional detect activity for Class B vehicles.	Vehicle-to-TMS data transfer includes the following: There is no additional detect activity for Class B vehicles.	Vehicle-to-TMS data transfer includes the following: There is no additional detect activity for Class B vehicles.	Vehicle-to-TMS data transfer includes the following: There is no additional detect activity for Class B vehicles.	Vehicle-to-TMS data transfer includes the following: There is no additional detect activity for Class B vehicles.	Vehicle-to-TMS data transfer includes the following: There is no additional detect activity for Class B vehicles.
Detect	B	V2V data transfer includes the following: There is no additional detect activity for Class B vehicles.	V2V data transfer includes the following: There is no additional detect activity for Class B vehicles.	V2V data transfer includes the following: There is no additional detect activity for Class B vehicles.	V2V data transfer includes the following: There is no additional detect activity for Class B vehicles.	V2V data transfer includes the following: There is no additional detect activity for Class B vehicles.	V2V data transfer includes the following: There is no additional detect activity for Class B vehicles.
Detect	C	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.
Detect	C	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.
Detect	C	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.
Verify	No cooperative automation	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.
Verify	A	TMS internal data transfer includes the following: 1. Visually by operators directly or via video (CCTVs). 2. Machine learning and AI tools to verify breakdowns.	TMS internal data transfer includes the following: 1. Visually by operators directly or via video (CCTVs). 2. Machine learning and AI tools to verify breakdowns.	TMS internal data transfer includes the following: 1. Visually by operators directly or via video (CCTVs). 2. Machine learning and AI tools to verify breakdowns.	TMS internal data transfer includes the following: 1. Visually by operators directly or via video (CCTVs). 2. Machine learning and AI tools to verify breakdowns.	TMS internal data transfer includes the following: 1. Visually by operators directly or via video (CCTVs). 2. Machine learning and AI tools to verify breakdown.	TMS internal data transfer includes the following: 1. Visually by operators directly or via video (CCTVs). 2. Machine learning and AI tools to verify breakdowns.

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Verify	A	Vehicle-to-TMS data transfer includes the following: Detection of hard braking, sudden heading changes, ABS activation, or abnormal change in vehicle speeds of several vehicles in close vicinity and direction.	Vehicle-to-TMS data transfer includes the following: Detection of hard braking, sudden heading changes, ABS activation, or abnormal change in vehicle speeds of several vehicles in close vicinity and direction.	Vehicle-to-TMS data transfer includes the following: Detection of hard braking, sudden heading changes, ABS activation, or abnormal change in vehicle speeds of several vehicles in close vicinity and direction.	Vehicle-to-TMS data transfer includes the following: Detection of hard braking, sudden heading changes, ABS activation, or abnormal change in vehicle speeds of several vehicles in close vicinity and direction.	Vehicle-to-TMS data transfer includes the following: Detection of hard braking, sudden heading changes, ABS activation, or abnormal change in vehicle speeds of several vehicles in close vicinity and direction.	Vehicle-to-TMS data transfer includes the following: Detection of hard braking, sudden heading changes, ABS activation, or abnormal change in vehicle speeds of several vehicles in close vicinity and direction.
Verify	A	V2V data transfer includes the following: 1. Several vehicles broadcast the same crash/disabled vehicle data obtained from other vehicles driving in same or opposite direction. Data potentially include pictures of involved vehicles. 2. If vehicle broadcasting crash/disabled vehicle data is involved in crash, it is assumed this broadcast serves as a primary verification.	V2V data transfer includes the following: 1. Several vehicles broadcast the same crash/disabled vehicle data obtained from other vehicles driving in same or opposite direction. Data potentially include pictures of involved vehicles. 2. If vehicle broadcasting crash/disabled vehicle data is involved in crash, it is assumed this broadcast serves as a primary verification.	V2V data transfer includes the following: 1. Several vehicles broadcast the same crash/disabled vehicle data obtained from other vehicles driving in same or opposite direction. Data potentially include pictures of involved vehicles. 2. If vehicle broadcasting crash/disabled vehicle data is involved in crash, it is assumed this broadcast serves as a primary verification.	V2V data transfer includes the following: 1. Several vehicles broadcast the same crash/disabled vehicle data obtained from other vehicles driving in same or opposite direction. Data potentially include pictures of involved vehicles. 2. If vehicle broadcasting crash/disabled vehicle data is involved in crash, it is assumed this broadcast serves as a primary verification.	V2V data transfer includes the following: 1. Several vehicles broadcast the same crash/disabled vehicle data obtained from other vehicles driving in same or opposite direction. Data potentially include pictures of involved vehicles. 2. If vehicle broadcasting crash/disabled vehicle data is involved in crash, it is assumed this broadcast serves as a primary verification.	V2V data transfer includes the following: 1. Several vehicles broadcast the same crash/disabled vehicle data obtained from other vehicles driving in same or opposite direction. Data potentially includes picture of involved vehicles. 2. If vehicle broadcasting crash/disabled vehicle data is involved in crash, it is assumed this broadcast serves as a primary verification.
Verify	B	Vehicle-to-TMS data transfer includes the following: There is no additional verify activity for Class B vehicles.	Vehicle-to-TMS data transfer includes the following: There is no additional verify activity for Class B vehicles.	Vehicle-to-TMS data transfer includes the following: There is no additional verify activity for Class B vehicles.	Vehicle-to-TMS data transfer includes the following: There is no additional verify activity for Class B vehicles.	Vehicle-to-TMS data transfer includes the following: There is no additional verify activity for Class B vehicles.	Vehicle-to-TMS data transfer includes the following: There is no additional verify activity for Class B vehicles.
Verify	B	V2V data transfer includes the following: There is no additional verify activity for Class B vehicles.	V2V data transfer includes the following: There is no additional verify activity for Class B vehicles.	V2V data transfer includes the following: There is no additional verify activity for Class B vehicles.	V2V data transfer includes the following: There is no additional verify activity for Class B vehicles.	V2V data transfer includes the following: There is no additional verify activity for Class B vehicles.	V2V data transfer includes the following: There is no additional verify activity for Class B vehicles.
Verify	C	Vehicle-to-TMS data transfer includes the following: There is no additional verify activity for Class B vehicles.	Vehicle-to-TMS data transfer includes the following: There is no additional verify activity for Class B vehicles.	Vehicle-to-TMS data transfer includes the following: There is no additional verify activity for Class B vehicles.	Vehicle-to-TMS data transfer includes the following: There is no additional verify activity for Class B vehicles.	Vehicle-to-TMS data transfer includes the following: There is no additional verify activity for Class B vehicles.	Vehicle-to-TMS data transfer includes the following: There is no additional verify activity for Class B vehicles.
Verify	C	V2V data transfer includes the following: There is no additional verify activity for Class B vehicles.	V2V data transfer includes the following: There is no additional verify activity for Class B vehicles.	V2V data transfer includes the following: There is no additional verify activity for Class B vehicles.	V2V data transfer includes the following: There is no additional verify activity for Class B vehicles.	V2V data transfer includes the following: There is no additional verify activity for Class B vehicles.	V2V data transfer includes the following: There is no additional verify activity for Class B vehicles.
Notify and advise	No cooperative automation	Operate as TMSs currently do, without automation and/or cooperation between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or cooperation between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or cooperation between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or cooperation between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or cooperation between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or cooperation between TMSs and vehicles.

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Notify and advise	A	TMS-to-vehicle data transfer includes the following: 1. Provide incident-related information pretrip or en route. En route provided via 511, FM radio, highway advisory radio, or DMS. 2. Broadcast information also to partner agencies that need to be informed and/or involved in incident response. 3. Machine learning and AI tools to create and execute incident notifications. 4. Broadcast data, including geofence and direction, details on the incident, dynamic speed harmonization, and applicable detour information (different message contents for responder vehicles versus other vehicles). 5. Broadcast queue warning.	TMS-to-vehicle data transfer includes the following: There is no additional notify and advise activity for Class A vehicles.	TMS-to-vehicle data transfer includes the following: There is no additional notify and advise activity for Class A vehicles.	TMS-to-vehicle data transfer includes the following: There is no additional notify and advise activity for Class A vehicles.	TMS-to-vehicle data transfer includes the following: There is no additional notify and advise activity for Class A vehicles.	TMS-to-vehicle data transfer includes the following: There is no additional notify and advise activity for Class A vehicles.
Notify and advise	A	V2V data transfer includes the following: If a vehicle receives incident notification from another vehicle or TMS, it will judiciously rebroadcast this information to provide early warning to other approaching vehicles farther upstream (judgment involves limited distance upstream and limited frequency, based on activity of rebroadcasts from other vehicles).	V2V data transfer includes the following: There is no additional notify and advise activity for Class A vehicles.	V2V data transfer includes the following: There is no additional notify and advise activity for Class A vehicles.	V2V data transfer includes the following: There is no additional notify and advise activity for Class A vehicles.	V2V data transfer includes the following: There is no additional notify and advise activity for Class A vehicles.	V2V data transfer includes the following: There is no additional notify and advise activity for Class A vehicles.
Notify and advise	B	TMS-to-vehicle data transfer includes the following: There is no additional notify and advise activity for Class B vehicles.	TMS-to-vehicle data transfer includes the following: There is no additional notify and advise activity for Class B vehicles.	TMS-to-vehicle data transfer includes the following: There is no additional notify and advise activity for Class B vehicles.	TMS-to-vehicle data transfer includes the following: There is no additional notify and advise activity for Class B vehicles.	TMS-to-vehicle data transfer includes the following: There is no additional notify and advise activity for Class B vehicles.	TMS-to-vehicle data transfer includes the following: There is no additional notify and advise activity for Class B vehicles.
Notify and advise	B	V2V data transfer includes the following: There is no additional notify and advise activity for Class B vehicles.	V2V data transfer includes the following: There is no additional notify and advise activity for Class B vehicles.	V2V data transfer includes the following: There is no additional notify and advise activity for Class B vehicles.	V2V data transfer includes the following: There is no additional notify and advise activity for Class B vehicles.	V2V data transfer includes the following: There is no additional notify and advise activity for Class B vehicles.	V2V data transfer includes the following: There is no additional notify and advise activity for Class B vehicles.
Notify and advise	C	TMS-to-vehicle data transfer includes the following: TMS sends notifications to vehicles that network is being load balanced along with details of a recommended detour route (generally applicable to Automation Level 3 and higher only but could theoretically apply to Level 0 through Level 2 vehicles).	TMS-to-vehicle data transfer includes the following: TMS sends notifications to vehicles that network is being load balanced along with details of a recommended detour route (generally applicable to Automation Level 3 and higher only but could theoretically apply to Level 0 through Level 2 vehicles).	TMS-to-vehicle data transfer includes the following: TMS sends notifications to vehicles that network is being load balanced along with details of a recommended detour route (generally applicable to Automation Level 3 and higher only but could theoretically apply to Level 0 through Level 2 vehicles).	TMS-to-vehicle data transfer includes the following: TMS sends notifications to vehicles that network is being load balanced along with details of a recommended detour route (generally applicable to Automation Level 3 and higher only but could theoretically apply to Level 0 through Level 2 vehicles).	TMS-to-vehicle data transfer includes the following: TMS sends notifications to vehicles that network is being load balanced along with details of a recommended detour route (generally applicable to Automation Level 3 and higher only but could theoretically apply to Level 0 through Level 2 vehicles).	TMS-to-vehicle data transfer includes the following: TMS sends notifications to vehicles that network is being load balanced along with details of a recommended detour route (generally applicable to Automation Level 3 and higher only but could theoretically apply to Level 0 through Level 2 vehicles).

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Notify and advise	C	Vehicle-to-TMS data transfer includes the following: Vehicle sends acknowledgment of load-balancing instructions to TMS and response as to what route it intends to take (generally applicable to Automation Levels 3 and higher only but could theoretically apply to Level 0 through Level 2 vehicles).	Vehicle-to-TMS data transfer includes the following: Vehicle sends acknowledgment of load-balancing instructions to TMS and response as to what route it intends to take (generally applicable to Automation Levels 3 and higher only but could theoretically apply to Level 0 through Level 2 vehicles).	Vehicle-to-TMS data transfer includes the following: Vehicle sends acknowledgment of load-balancing instructions to TMS and response as to what route it intends to take (generally applicable to Automation Levels 3 and higher only but could theoretically apply to Level 0 through Level 2 vehicles).	Vehicle-to-TMS data transfer includes the following: Vehicle sends acknowledgment of load-balancing instructions to TMS and response as to what route it intends to take (generally applicable to Automation Levels 3 and higher only but could theoretically apply to Level 0 through Level 2 vehicles).	Vehicle-to-TMS data transfer includes the following: Vehicle sends acknowledgment of load-balancing instructions to TMS and response as to what route it intends to take (generally applicable to Automation Levels 3 and higher only but could theoretically apply to Level 0 through Level 2 vehicles).	Vehicle-to-TMS data transfer includes the following: Vehicle sends acknowledgment of load-balancing instructions to TMS and response as to what route it intends to take (generally applicable to Automation Levels 3 and higher only but could theoretically apply to Level 0 through Level 2 vehicles).
Notify and advise	C	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following in addition to Class A: If a vehicle is approaching an incident and cognizant of the incident, the driver is instructed to assume vehicle control, manually negotiating lane merges as necessary to avoid the incident lanes and/or redirect to detour route.	V2V data transfer includes the following in addition to Class A: If a vehicle is approaching an incident and cognizant of the incident, negotiate lane merges as necessary to avoid the incident lanes and/or to redirect to detour route.	V2V data transfer includes the following in addition to Class A: If a vehicle is approaching an incident and cognizant of the incident, negotiate lane merges as necessary to avoid the incident lanes and/or to redirect to detour route.
Respond	No cooperative automation	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.
Respond	A	TMS internal data transfer includes the following: Using preestablished SOPs, first responders and tow trucks are notified to broadcast their vehicle data.	TMS internal data transfer includes the following: Using preestablished SOPs, first responders and tow trucks are notified to broadcast their vehicle data.	TMS internal data transfer includes the following: Using preestablished SOPs, first responders and tow trucks are notified to broadcast their vehicle data.	TMS internal data transfer includes the following: Using preestablished SOPs, first responders and tow trucks are notified to broadcast their vehicle data.	TMS internal data transfer includes the following: Using preestablished SOPs, first responders and tow trucks are notified to broadcast their vehicle data.	TMS internal data transfer includes the following: Using preestablished SOPs, first responders and tow trucks are notified to broadcast their vehicle data.
Respond	A	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast location data and speeds providing any changes to the TMS (both vehicles and first responders). 2. Broadcast other vehicle data, such as vehicle-detected environment-related information.	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast location data and speeds providing any changes to the TMS (both vehicles and first responders). 2. Broadcast other vehicle data, such as vehicle-detected environment-related information.	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast location data and speeds providing any changes to the TMS (both vehicles and first responders). 2. Broadcast other vehicle data, such as vehicle-detected environment-related information.	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast location data and speeds providing any changes to the TMS (both vehicles and first responders). 2. Broadcast other vehicle data, such as vehicle-detected environment-related information.	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast location data and speeds providing any changes to the TMS (both vehicles and first responders). 2. Broadcast other vehicle data, such as vehicle-detected environment-related information.	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast location data and speeds providing any changes to the TMS (both vehicles and first responders). 2. Broadcast other vehicle data, such as vehicle-detected environment-related information.
Respond	A	TMS-to-vehicle data transfer includes the following: 1. Broadcast geofence with a TMS-defined safe speed approaching incident site and/or to follow TMS-defined turn-by-turn detours to avoid incident site. 2. Broadcast route guidance details (considering traffic conditions) to responder vehicles.	TMS-to-vehicle data transfer includes the following: 1. Broadcast geofence with a TMS-defined safe speed approaching incident site and/or to follow TMS-defined turn-by-turn detours to avoid incident site. 2. Broadcast route guidance details (considering traffic conditions) to responder vehicles.	TMS-to-vehicle data transfer includes the following: 1. Broadcast geofence with a TMS-defined safe speed approaching incident site and/or to follow TMS-defined turn-by-turn detours to avoid incident site. 2. Broadcast route guidance details (considering traffic conditions) to responder vehicles.	TMS-to-vehicle data transfer includes the following: 1. Broadcast geofence with a TMS-defined safe speed approaching incident site and/or to follow TMS-defined turn-by-turn detours to avoid incident site. 2. Broadcast route guidance details (considering traffic conditions) to responder vehicles.	TMS-to-vehicle data transfer includes the following: 1. Broadcast geofence with a TMS-defined safe speed approaching incident site and/or to follow TMS-defined turn-by-turn detours to avoid incident site. 2. Broadcast route guidance details (considering traffic conditions) to responder vehicles.	TMS-to-vehicle data transfer includes the following: 1. Broadcast geofence with a TMS-defined safe speed approaching incident site and/or to follow TMS-defined turn-by-turn detours to avoid incident site. 2. Broadcast route guidance details (considering traffic conditions) to responder vehicles.

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Respond	A	V2V data transfer includes the following: Continuously broadcast location data, speeds, headings, and other vehicle data, such as vehicle-detected environment-related information, and provide any changes to other vehicles (for both vehicles and first responders).	V2V data transfer includes the following: Continuously broadcast location data, speeds, headings, and other vehicle data, such as vehicle-detected environment-related information, and provide any changes to other vehicles (for both vehicles and first responders).	V2V data transfer includes the following: Continuously broadcast location data, speeds, headings, and other vehicle data, such as vehicle-detected environment-related information, and provide any changes to other vehicles (for both vehicles and first responders).	V2V data transfer includes the following: Continuously broadcast location data, speeds, headings, and other vehicle data, such as vehicle-detected environment-related information, and provide any changes to other vehicles (for both vehicles and first responders).	V2V data transfer includes the following: Continuously broadcast location data, speeds, headings, and other vehicle data, such as vehicle-detected environment-related information, and provide any changes to other vehicles (for both vehicles and first responders).	V2V data transfer includes the following: Continuously broadcast location data, speeds, headings, and other vehicle data, such as vehicle-detected environment-related information, and provide any changes to other vehicles (for both vehicles and first responders).
Respond	B	TMS-to-vehicle data transfer includes the following in addition to Class A: Broadcast responder vehicle's approach data to vehicles already queued up before incident site with instructions to move out of the way.	TMS-to-vehicle data transfer includes the following in addition to Class A: Broadcast responder vehicle's approach data to vehicles already queued up before incident site with instructions to move out of the way.	TMS-to-vehicle data transfer includes the following in addition to Class A: Broadcast responder vehicle's approach data to vehicles already queued up before incident site with instructions to move out of the way.	TMS-to-vehicle data transfer includes the following in addition to Class A: Broadcast responder vehicle's approach data to vehicles already queued up before incident site with instructions to move out of the way.	TMS-to-vehicle data transfer includes the following in addition to Class A and Level 0 through Level 3: Broadcast suggestions to follow TMS-defined detours within geofenced areas, allowing for limited network load-balancing.	TMS-to-vehicle data transfer includes the following in addition to Class A and Level 4: Broadcast suggestions to follow TMS-defined detours within geofenced areas, allowing for network load-balancing for the entire TMS coverage area.
Respond	B	Vehicle-to-TMS data transfer includes the following in addition to Class A: First responders on scene can better determine necessary traffic parameters than those broadcasted in the TMS geofence, or in case the TMS does not yet have enough information to broadcast a geofence, a first responder vehicle may locally broadcast an in-field geofence devised by its operators, which could then be picked up and rebroadcast by the TMS.	Vehicle-to-TMS data transfer includes the following in addition to Class A: First responders on scene can better determine necessary traffic parameters than those broadcasted in the TMS geofence, or in case the TMS does not yet have enough information to broadcast a geofence, a first responder vehicle may locally broadcast an in-field geofence devised by its operators, which could then be picked up and rebroadcast by the TMS.	Vehicle-to-TMS data transfer includes the following in addition to Class A: First responders on scene can better determine necessary traffic parameters than those broadcasted in the TMS geofence, or in case the TMS does not yet have enough information to broadcast a geofence, a first responder vehicle may locally broadcast an in-field geofence devised by its operators, which could then be picked up and rebroadcast by the TMS.	Vehicle-to-TMS data transfer includes the following in addition to Class A: First responders on scene can better determine necessary traffic parameters than those broadcasted in the TMS geofence, or in case the TMS does not yet have enough information to broadcast a geofence, a first responder vehicle may locally broadcast an in-field geofence devised by its operators, which could then be picked up and rebroadcast by the TMS.	Vehicle-to-TMS data transfer includes the following in addition to Class A: First responders on scene can better determine necessary traffic parameters than those broadcasted in the TMS geofence, or in case the TMS does not yet have enough information to broadcast a geofence, a first responder vehicle may locally broadcast an in-field geofence devised by its operators, which could then be picked up and rebroadcast by the TMS.	Vehicle-to-TMS data transfer includes the following in addition to Class A: First responders on scene can better determine necessary traffic parameters than those broadcasted in the TMS geofence, or in case the TMS does not yet have enough information to broadcast a geofence, a first responder vehicle may locally broadcast an in-field geofence devised by its operators, which could then be picked up and rebroadcast by the TMS.
Respond	B	V2V data transfer includes the following in addition to Class A: Receive trajectory data from neighboring vehicles and first responder vehicles. This information can be displayed to the human operator to aid in decision making about how to make room for first responders or, If a vehicle is a first responder, how best to navigate through other vehicles that may be attempting to make room.	V2V data transfer includes the following in addition to Class A: Receive trajectory data from neighboring vehicles and first responder vehicles. This information can be displayed to the human operator to aid in decision making about how to make room for first responders or, If a vehicle is a first responder, how best to navigate through other vehicles that may be attempting to make room.	V2V data transfer includes the following in addition to Class A and Level 0 through Level 1: 1. Emergency responders broadcast their intended trajectories as they approach the scene, which will be dependent upon their receipt of trajectory plans from other Class B or higher vehicles in the vicinity. 2. Vehicles in vicinity observe first responder vehicles' intended trajectories, plan own trajectories to clear a path, and broadcast these plans for other vehicles' awareness.	V2V data transfer includes the following in addition to Class A and Level 0 through Level 1: 1. Emergency responders broadcast their intended trajectories as they approach the scene, which will be dependent upon their receipt of trajectory plans from other Class B or higher vehicles in the vicinity. 2. Vehicles in vicinity observe first responder vehicles' intended trajectories, plan own trajectories to clear a path, and broadcast these plans for other vehicles' awareness.	V2V data transfer includes the following in addition to Class A and Level 0 through Level 1: 1. Emergency responders broadcast their intended trajectories as they approach the scene, which will be dependent upon their receipt of trajectory plans from other Class B or higher vehicles in the vicinity. 2. Vehicles in vicinity observe first responder vehicles' intended trajectories, plan own trajectories to clear a path, and broadcast these plans for other vehicles' awareness.	V2V data transfer includes the following in addition to Class A and Level 0 through Level 1: 1. Emergency responders broadcast their intended trajectories as they approach the scene, which will be dependent upon their receipt of trajectory plans from other Class B or higher vehicles in the vicinity. 2. Vehicles in vicinity observe first responder vehicles' intended trajectories, plan own trajectories to clear a path, and broadcast these plans for other vehicles' awareness.
Respond	C	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Respond	C	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.
Respond	C	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following in addition to Class B: 1. First responders actively negotiate with each other to determine a coordinated approach and configuration for the incident area, assuming that other vehicles will yield to them. 2. Vehicles receive trajectory plans from first responders, transmit acknowledgments that they respect first responders' priority and plan to clear a path. 3. Vehicles negotiate with each other for cooperative movements to quickly clear a path for first responders while avoiding further collisions, and to safely resume normal driving once first responders have passed. 4. Vehicles negotiate with each other to cooperate in changing lanes, speeds, platooning parameters, and so on, as necessary to pass the incident according to the temporary rules set up by the deployed geofences and the travel direction.	V2V data transfer includes the following: Same as Level 2 for this operational action.	V2V data transfer includes the following: Same as Level 2 for this operational action.	V2V data transfer includes the following: Same as Level 2 for this operational action.
Manage site	No cooperative automation	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.
Manage site	A	TMS internal data transfer includes the following: 1. Monitor status and performance of field devices and location of responder vehicles. 2. Accurate assessment of incident.	TMS internal data transfer includes the following: 1. Monitor status and performance of field devices and location of responder vehicles. 2. Accurate assessment of incident.	TMS internal data transfer includes the following: 1. Monitor status and performance of field devices and location of responder vehicles. 2. Accurate assessment of incident.	TMS internal data transfer includes the following: 1. Monitor status and performance of field devices and location of responder vehicles. 2. Accurate assessment of incident.	TMS internal data transfer includes the following: 1. Monitor status and performance of field devices and location of responder vehicles. 2. Accurate assessment of incident.	TMS internal data transfer includes the following: 1. Monitor status and performance of field devices and location of responder vehicles. 2. Accurate assessment of incident.
Manage site	A	TMS-to-vehicle data transfer includes the following: Continuously broadcast updated information about incident site.	TMS-to-vehicle data transfer includes the following: Continuously broadcast updated information about incident site.	TMS-to-vehicle data transfer includes the following: Continuously broadcast updated information about incident site.	TMS-to-vehicle data transfer includes the following: Continuously broadcast updated information about incident site.	TMS-to-vehicle data transfer includes the following: Continuously broadcast updated information about incident site.	TMS-to-vehicle data transfer includes the following: Continuously broadcast updated information about incident site.

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Manage site	A	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast location data and speeds providing any changes to the TMS (e.g., vehicles following detour suggestions), as well as weather-related data. 2. First responders on scene continue to inform TMS of their exact locations and situations, as well as changes in configuration of affected zone; this allows the TMS to update the geofence and other information being broadcast.	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast location data and speeds providing any changes to the TMS (e.g., vehicles following detour suggestions), as well as weather-related data. 2. First responders on scene continue to inform TMS of their exact locations and situations, as well as changes in configuration of affected zone; this allows the TMS to update the geofence and other information being broadcast.	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast location data and speeds providing any changes to the TMS (e.g., vehicles following detour suggestions), as well as weather-related data. 2. First responders on scene continue to inform TMS of their exact locations and situations, as well as changes in configuration of affected zone; this allows the TMS to update the geofence and other information being broadcast.	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast location data and speeds providing any changes to the TMS (e.g., vehicles following detour suggestions), as well as weather-related data. 2. First responders on scene continue to inform TMS of their exact locations and situations, as well as changes in configuration of affected zone; this allows the TMS to update the geofence and other information being broadcast.	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast location data and speeds providing any changes to the TMS (e.g., vehicles following detour suggestions), as well as weather-related data. 2. First responders on scene continue to inform TMS of their exact locations and situations, as well as changes in configuration of affected zone; this allows the TMS to update the geofence and other information being broadcast.	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast location data and speeds providing any changes to the TMS (e.g., vehicles following detour suggestions), as well as weather-related data. 2. First responders on scene continue to inform TMS of their exact locations and situations, as well as changes in configuration of affected zone; this allows the TMS to update the geofence and other information being broadcast.
Manage site	A	V2V data transfer includes the following: First responder vehicles operating at incident site continue to inform other vehicles of their exact locations and situations, as well as changes in the configuration of site.	V2V data transfer includes the following: First responder vehicles operating at incident site continue to inform other vehicles of their exact locations and situations, as well as changes in the configuration of site.	V2V data transfer includes the following: First responder vehicles operating at incident site continue to inform other vehicles of their exact locations and situations, as well as changes in the configuration of site.	V2V data transfer includes the following: First responder vehicles operating at incident site continue to inform other vehicles of their exact locations and situations, as well as changes in the configuration of site.	V2V data transfer includes the following: First responder vehicles operating at incident site continue to inform other vehicles of their exact locations and situations, as well as changes in the configuration of site.	V2V data transfer includes the following: First responder vehicles operating at incident site continue to inform other vehicles of their exact locations and situations, as well as changes in the configuration of site.
Manage site	B	TMS-to-vehicle data transfer includes the following: In addition to Class A: Transmit proper staging location to responder vehicle.	TMS-to-vehicle data transfer includes the following: In addition to Class A: Transmit proper staging location to responder vehicle.	TMS-to-vehicle data transfer includes the following: In addition to Class A: Transmit proper staging location to responder vehicle.	TMS-to-vehicle data transfer includes the following: In addition to Class A: Transmit proper staging location to responder vehicle.	TMS-to-vehicle data transfer includes the following: In addition to Class A: Transmit proper staging location to responder vehicle.	TMS-to-vehicle data transfer includes the following: In addition to Class A: Transmit proper staging location to responder vehicle.
Manage site	B	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.
Manage site	B	V2V data transfer includes the following: Same as first responder vehicles in the respond operational action.	V2V data transfer includes the following: Same as first responder vehicles in the respond operational action.	V2V data transfer includes the following: Same as first responder vehicles in the respond operational action.	V2V data transfer includes the following: Same as first responder vehicles in the respond operational action.	V2V data transfer includes the following: Same as first responder vehicles in the respond operational action.	V2V data transfer includes the following: Same as first responder vehicles in the respond operational action.
Manage site	C	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.
Manage site	C	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.
Manage site	C	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.
Manage traffic	No cooperative automation	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Manage traffic	A	TMC Internal data transfer includes the following: 1. Activate detours. 2. Set up traffic control devices at incident location. 3. Monitor travel conditions around incident (status of lanes blocked/cleared, field devices, location of responders, and determination of queues) and on freeways and arterials (travel times and level of service).	TMC Internal data transfer includes the following in addition to Level 0: Provide more details regarding incident layout, including location of cones for merging, configuration of end of incident site, and how to navigate it (important because lane delineations might no longer be valid).	TMC Internal data transfer includes the following in addition to Level 0: Provide more details regarding incident layout, including location of cones for merging, configuration of end of incident site, and how to navigate it (important because lane delineations might no longer be valid).	TMC Internal data transfer includes the following in addition to Level 0: Provide more details regarding incident layout, including location of cones for merging, configuration of end of incident site, and how to navigate it (important because lane delineations might no longer be valid).	TMC Internal data transfer includes the following in addition to Level 0: Provide more details regarding incident layout, including location of cones for merging, configuration of end of incident site, and how to navigate it (important because lane delineations might no longer be valid).	TMC Internal data transfer includes the following in addition to Level 0: Provide more details regarding incident layout, including location of cones for merging, configuration of end of incident site, and how to navigate it (important because lane delineations might no longer be valid).
Manage traffic	A	TMS-to-vehicle data transfer includes the following: 1. Create and broadcast geographic layout of incident site (MAP). 2. Continuously broadcast updates of incident activities affecting approaching vehicles (location of first responder vehicles, employees, estimated incident duration, weather changes, and so on).	TMS-to-vehicle data transfer includes the following: 1. Create and broadcast geographic layout of incident site (MAP). 2. Continuously broadcast updates of incident activities affecting approaching vehicles (location of first responder vehicles, employees, estimated incident duration, weather changes, and so on).	TMS-to-vehicle data transfer includes the following: 1. Create and broadcast geographic layout of incident site (MAP). 2. Continuously broadcast updates of incident activities affecting approaching vehicles (location of first responder vehicles, employees, estimated incident duration, weather changes, and so on).	TMS-to-vehicle data transfer includes the following in addition to Level 0 through Level 2: 1. Activate detours. 2. Set up traffic control devices at incident location. 3. Monitor travel conditions around incident (status of lanes blocked/cleared, field devices, location of responders, and determination of queues) and on freeways and arterials (travel times and level of service). 4. Provide more details regarding incident layout, including location of cones for merging, layout of end of incident site, and how to navigate it (important because lane delineations might no longer be valid). 5. Transmit notification to vehicle to inform driver to assume control when approaching incident location. (Not clear whether this is a vehicle-internal decision based on location.)	TMS-to-vehicle data transfer includes the following in addition to Level 0 through Level 2: 1. Activate detours. 2. Set up traffic control devices at incident location. 3. Monitor travel conditions around incident (status of lanes blocked/cleared, field devices, location of responders, and determination of queues) and on freeways and arterials (travel times and level of service). 4. Provide more details regarding incident layout, including location of cones for merging, layout of end of incident site, and how to navigate it (important because lane delineations might no longer be valid). 5. Create and broadcast updates of geographic layout of incident site (MAP). (Note that at this Automation Level, the TMC does not need to send a notification to driver to assume vehicle control).	TMS-to-vehicle data transfer includes the following in addition to Level 0 through Level 2: 1. Activate detours. 2. Set up traffic control devices at incident location. 3. Monitor travel conditions around incident (status of lanes blocked/cleared, field devices, location of responders, and determination of queues) and on freeways and arterials (travel times and level of service). 4. Provide more details regarding incident layout, including location of cones for merging, layout of end of incident site, and how to navigate it (important because lane delineations might no longer be valid). 5. Create and broadcast updates of geographic layout of incident site (MAP). (Note that at this Automation Level, the TMC does not need to send a notification to driver to assume vehicle control).
Manage traffic	A	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds, providing any changes to TMS.	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds, providing any changes to TMS.	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds, providing any changes to TMS.	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds, providing any changes to TMS.	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds, providing any changes to TMS.	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds, providing any changes to TMS.
Manage traffic	A	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.
Manage traffic	B	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Manage traffic	B	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.
Manage traffic	B	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: Maneuvering is performed in accordance with rules established by any deployed geofences and travel direction.	V2V data transfer includes the following: Vehicles broadcast their intentions and observe those of neighboring vehicles. They develop trajectories to politely maneuver within the traffic stream that they understand from their neighbors' plans. Maneuvering is performed in accordance with rules established by deployed geofences and travel direction.	V2V data transfer includes the following: Vehicles broadcast their intentions and observe those of neighboring vehicles. They develop trajectories to politely maneuver within the traffic stream that they understand from their neighbors' plans. Maneuvering is performed in accordance with rules established by deployed geofences and travel direction.	V2V data transfer includes the following: Vehicles broadcast their intentions and observe those of neighboring vehicles. They develop trajectories to politely maneuver within the traffic stream that they understand from their neighbors' plans. Maneuvering is performed in accordance with rules established by deployed geofences and travel direction.	V2V data transfer includes the following: Vehicles broadcast their intentions and observe those of neighboring vehicles. They develop trajectories to politely maneuver within the traffic stream that they understand from their neighbors' plans. Maneuvering is performed in accordance with rules established by deployed geofences and travel direction.
Manage traffic	C	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.
Manage traffic	C	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.
Manage traffic	C	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.
Clear and terminate event	No cooperative automation	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.
Clear and terminate event	A	TMS internal data transfer includes the following: Collecting/removing wreckage, debris, and so on from affected roadway lanes.	TMS internal data transfer includes the following: Collecting/removing wreckage, debris, and so on from affected roadway lanes.	TMS internal data transfer includes the following: Collecting/removing wreckage, debris, and so on from affected roadway lanes.	TMS internal data transfer includes the following: Collecting/removing wreckage, debris, and so on from affected roadway lanes.	TMS internal data transfer includes the following: Collecting/removing wreckage, debris, and so on from affected roadway lanes.	TMS internal data transfer includes the following: Collecting/removing wreckage, debris, and so on from affected roadway lanes.
Clear and terminate event	A	TMS-to-vehicle data transfer includes the following 1. Collect/remove wreckage, debris, and so on from affected roadway lanes. 2. Create and broadcast geographic layout of changing incident site (MAP). 3. Continuously broadcast updates of incident activities affecting approaching vehicles (new location of first responder vehicles, employees, estimated incident duration, weather changes).	TMS-to-vehicle data transfer includes the following: 1. Collect/remove wreckage, debris, and so on from affected roadway lanes. 2. Create and broadcast geographic layout of changing incident site (MAP). 3. Continuously broadcast updates of incident activities affecting approaching vehicles (new location of first responder vehicles, employees, estimated incident duration, weather changes).	TMS-to-vehicle data transfer includes the following: 1. Collect/remove wreckage, debris, and so on from affected roadway lanes. 2. Create and broadcast geographic layout of changing incident site (MAP). 3. Continuously broadcast updates of incident activities affecting approaching vehicles (new location of first responder vehicles, employees, estimated incident duration, weather changes).	TMS-to-vehicle data transfer includes the following in addition to Level 0 through Level 2: Transmit notification to vehicle to inform driver that vehicle is ready to resume control after incident location is cleared, i.e., previously blocked lanes are available again. (Not clear whether this is a vehicle-internal decision based on location.)	TMS-to-vehicle data transfer includes the following in addition to Level 0 through Level 2: Create and broadcast updates of geographic layout of incident site (MAP). (Note that at this Automation Level, the TMC does not need to send a notification to driver to assume vehicle control).	TMS-to-vehicle data transfer includes the following in addition to Level 0 through Level 2: Create and broadcast updates of geographic layout of incident site (MAP). (Note that at this Automation Level, the TMC does not need to send a notification to driver to assume vehicle control).

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Clear and terminate event	A	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds providing any changes to the TMS (indicates incident clearance at site, when responder vehicles leave).	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds providing any changes to the TMS (indicates incident clearance at site, when responder vehicles leave).	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds providing any changes to the TMS (indicates incident clearance at site, when responder vehicles leave).	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds providing any changes to the TMS (indicates incident clearance at site, when responder vehicles leave).	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds providing any changes to the TMS (indicates incident clearance at site, when responder vehicles leave).	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds providing any changes to the TMS (indicates incident clearance at site, when responder vehicles leave).
Clear and terminate event	A	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.
Clear and terminate event	B	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.
Clear and terminate event	B	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.
Clear and terminate event	B	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: Maneuvering is performed in accordance with rules established by deployed geofences and travel direction.	V2V data transfer includes the following: Vehicles broadcast their intentions and observe those of neighboring vehicles, including departing responders. They develop trajectories to politely maneuver within the traffic stream.	V2V data transfer includes the following: Vehicles broadcast their intentions and observe those of neighboring vehicles, including departing responders. They develop trajectories to politely maneuver within the traffic stream.	V2V data transfer includes the following: Vehicles broadcast their intentions and observe those of neighboring vehicles, including departing responders. They develop trajectories to politely maneuver within the traffic stream.	V2V data transfer includes the following: Vehicles broadcast their intentions and observe those of neighboring vehicles, including departing responders. They develop trajectories to politely maneuver within the traffic stream.
Clear and terminate event	C	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.
Clear and terminate event	C	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.
Clear and terminate event	C	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.
Recover	No cooperative automation	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Recover	A	TMS internal data transfer includes the following: 1. Update incident information including final debris removal and final opening of all lanes and shoulders. 2. Return to normal operations. 3. Capture and store all information received from transmitting vehicles.	TMS internal data transfer includes the following: 1. Update incident information including final debris removal and final opening of all lanes and shoulders. 2. Return to normal operations. 3. Capture and store all information received from transmitting vehicles.	TMS internal data transfer includes the following: 1. Update incident information including final debris removal and final opening of all lanes and shoulders. 2. Return to normal operations. 3. Capture and store all information received from transmitting vehicles.	TMS internal data transfer includes the following: 1. Update incident information including final debris removal and final opening of all lanes and shoulders. 2. Return to normal operations. 3. Capture and store all information received from transmitting vehicles.	TMS internal data transfer includes the following: 1. Update incident information including final debris removal and final opening of all lanes and shoulders. 2. Return to normal operations. 3. Capture and store all information received from transmitting vehicles.	TMS internal data transfer includes the following: 1. Update incident information including final debris removal and final opening of all lanes and shoulders. 2. Return to normal operations. 3. Capture and store all information received from transmitting vehicles.
Recover	A	TMS-to-vehicle data transfer includes the following: 1. Create and broadcast geographic layout of changing incident site (MAP). 2. Continuously broadcast updates of incident activities affecting approaching vehicles (new location of first responder vehicles, employees, estimated incident duration, weather changes, and so on).	TMS-to-vehicle data transfer includes the following: 1. Create and broadcast geographic layout of changing incident site (MAP). 2. Continuously broadcast updates of incident activities affecting approaching vehicles (new location of first responder vehicles, employees, estimated incident duration, weather changes, and so on).	TMS-to-vehicle data transfer includes the following: 1. Create and broadcast geographic layout of changing incident site (MAP). 2. Continuously broadcast updates of incident activities affecting approaching vehicles (new location of first responder vehicles, employees, estimated incident duration, weather changes, and so on).	TMS-to-vehicle data transfer includes the following in addition to Level 0 through Level 2: Transmit notification to vehicle to inform driver that vehicle is ready to resume control after incident location is cleared (i.e., previously blocked lanes are available again). (Not clear whether this is a vehicle-internal decision based on location.)	TMS-to-vehicle data transfer includes the following in addition to Level 0 through Level 2: Create and broadcast updates of geographic layout of former work zone site (i.e., the normal layout of the roadway (MAP)).	TMS-to-vehicle data transfer includes the following in addition to Level 0 through Level 2: Create and broadcast updates of geographic layout of former work zone site (i.e., the normal layout of the roadway (MAP)).
Recover	A	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds providing any changes to the TMS.	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds providing any changes to the TMS.	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds providing any changes to the TMS.	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds providing any changes to the TMS.	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds providing any changes to the TMS.	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds providing any changes to the TMS.
Recover	A	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.
Recover	B	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.
Recover	B	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.
Recover	B	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: Maneuvering is performed in accordance with rules established by deployed geofences and travel direction.	V2V data transfer includes the following: Vehicles broadcast their intentions and observe those of neighboring vehicles, including departing responders. They develop trajectories to politely maneuver within the traffic stream that they understand from their neighbors' plans. Maneuvering is performed in accordance with rules established by deployed geofences and travel direction.	V2V data transfer includes the following: Vehicles broadcast their intentions and observe those of neighboring vehicles, including departing responders. They develop trajectories to politely maneuver within the traffic stream that they understand from their neighbors' plans. Maneuvering is performed in accordance with rules established by deployed geofences and travel direction.	V2V data transfer includes the following: Vehicles broadcast their intentions and observe those of neighboring vehicles, including departing responders. They develop trajectories to politely maneuver within the traffic stream that they understand from their neighbors' plans. Maneuvering is performed in accordance with rules established by deployed geofences and travel direction.	V2V data transfer includes the following: Vehicles broadcast their intentions and observe those of neighboring vehicles, including departing responders. They develop trajectories to politely maneuver within the traffic stream that they understand from their neighbors' plans. Maneuvering is performed in accordance with rules established by deployed geofences and travel direction.

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Recover	C	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.
Recover	C	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action
Recover	C	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following in addition to Class B: Vehicles negotiate with each other, cooperatively reentering the newly opened lanes, changing lanes elsewhere, recovering speeds, reforming platoons, and so on, as necessary to pass the former incident site.	V2V data transfer includes the following in addition to Class B: Vehicles negotiate with each other, cooperatively reentering the newly opened lanes, changing lanes elsewhere, recovering speeds, reforming platoons, and so on, as necessary to pass the former incident site.	V2V data transfer includes the following in addition to Class B: Vehicles negotiate with each other, cooperatively reentering the newly opened lanes, changing lanes elsewhere, recovering speeds, reforming platoons, and so on, as necessary to pass the former incident site.	V2V data transfer includes the following in addition to Class B: Vehicles negotiate with each other, cooperatively reentering the newly opened lanes, changing lanes elsewhere, recovering speeds, reforming platoons, and so on, as necessary to pass the former incident site.

ABS = antilock braking system; AI = artificial intelligence; CCTV = closed-circuit television; HAZMAT = hazardous material; SOP = standard operating procedure.

Framework for RWM Use Case

From a TMS operations perspective, table 40 shows the information a TMS can provide to CDA vehicles during weather events, the information vehicles of different Automation Levels/Cooperation Classes can provide to a TMS during weather events, and the information vehicles with different Automation Levels/Cooperation Classes can provide between one another during weather events. This includes both the data gathered by a TMS and provided to the traveling public, State and local transit agencies, and third-party data users and providers and environmental data gathered by vehicles and provided to a TMS. A TMS will continue to provide relevant data to drivers as it does now.

For RWM, the TSMO-focused TMS operations are defined by those activities that TMSs, and especially TMCs, typically perform during weather events and other environmental anomalies. The operational actions associated with RWM are defined as follows:

- Detect—determining the pending, predicted appearance or existence of weather-related impacts to roadways and their users (drivers and vehicles). The detection can be performed by third-party data providers (e.g., National Oceanic and Atmospheric Administration, The Weather Channel), by roadside weather stations and their back-office systems, by simple human observations, including weather-related incident reports, or by specially equipped vehicles with weather and environmental sensors.
- Notify and advise—providing situational awareness information regarding current and near-term predicted road weather conditions to vehicles regardless of Automation Levels.
- Control—responding to near-term predicted and current road weather conditions to CDA via controlling field devices (e.g., DMSs, roadway gates), road-weather-response vehicles, and other potentially affected vehicles.
- Treat and maintain—treating roadway surfaces and/or applying other treatments, including road closures due to weather-related events. For CDA, a TMS and/or affiliated public entity can instruct fleet vehicles regarding the appropriate roadway surface treatment.

CDA-equipped vehicles encountering road weather conditions can exchange data about the weather conditions detected by a vehicle and provide the information to other CDA-equipped vehicles. V2V operations can exchange data much faster than a TMS between vehicles and follow procedures similar to the exchanges between TMSs and vehicles.

All content in table 40 is in addition to data determined by onboard sensing equipment that enable vehicles to detect, process, and react to obstacles and other vehicles and pedestrians in their path.

Table 40. Framework for TSMO within a CDA environment—RWM use case.

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Detect	No cooperative automation	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.
Detect	A	TMS internal data transfer includes the following: Various means to detect weather events, such as NOAA, The Weather Channel, third-party weather providers, or from RWIS (directly from the RWIS stations or from an RWIS central system).	TMS internal data transfer includes the following: Various means to detect weather events, such as NOAA, The Weather Channel, third-party weather providers, or from RWIS (directly from the RWIS stations or from an RWIS central system).	TMS internal data transfer includes the following: Various means to detect weather events, such as NOAA, The Weather Channel, third-party weather providers, or from RWIS (directly from the RWIS stations or from an RWIS central system).	TMS internal data transfer includes the following: Various means to detect weather events, such as NOAA, The Weather Channel, third-party weather providers, or from RWIS (directly from the RWIS stations or from an RWIS central system).	TMS internal data transfer includes the following: Various means to detect weather events, such as NOAA, The Weather Channel, third-party weather providers, or from RWIS (directly from the RWIS stations or from an RWIS central system).	TMS internal data transfer includes the following: Various means to detect weather events, such as NOAA, The Weather Channel, third-party weather providers, or from RWIS (directly from the RWIS stations or from an RWIS central system).
Detect	A	TMS-to-vehicle data transfer includes the following: 1. Set data to be reported by vehicle (situation data-collection parameters, vehicle-situation data parameters). 2. Acknowledge crash notification (emergency acknowledge).	TMS-to-vehicle data transfer includes the following: 1. Set data to be reported by vehicle (situation data-collection parameters, vehicle-situation data parameters). 2. Acknowledge crash notification (emergency acknowledge).	TMS-to-vehicle data transfer includes the following: 1. Set data to be reported by vehicle (situation data-collection parameters, vehicle-situation data parameters). 2. Acknowledge crash notification (emergency acknowledge).	TMS-to-vehicle data transfer includes the following: 1. Set data to be reported by vehicle (situation data-collection parameters, vehicle-situation data parameters). 2. Acknowledge crash notification (emergency acknowledge).	TMS-to-vehicle data transfer includes the following: 1. Set data to be reported by vehicle (situation data-collection parameters, vehicle-situation data parameters). 2. Acknowledge crash notification (emergency acknowledge).	TMS-to-vehicle data transfer includes the following: 1. Set data to be reported by vehicle (situation data-collection parameters, vehicle-situation data parameters). 2. Acknowledge crash notification (emergency acknowledge).
Detect	A	Vehicle-to-TMS data transfer includes the following: 1. Broadcast windshield wiper status, traction control status, braking status, air temperature, air pressure. 2. ABS engagement status. 3. Road surface data (likely only from special agency vehicles). 4. Winter-maintenance materials output by vehicle (likely only from special agency vehicles). 5. Status of snowplow blade (up/down) (likely only from special agency vehicles).	Vehicle-to-TMS data transfer includes the following: 1. Broadcast windshield wiper status, traction control status, braking status, air temperature, air pressure. 2. ABS engagement status 3. Road surface data (likely only from special agency vehicles). 4. Winter-maintenance materials output by vehicle (likely only from special agency vehicles). 5. Status of snowplow blade (up/down) (likely only from special agency vehicles).	Vehicle-to-TMS data transfer includes the following: 1. Broadcast windshield wiper status, traction control status, braking status, air temperature, air pressure. 2. ABS engagement status. 3. Road surface data (likely only from special agency vehicles). 4. Winter-maintenance materials output by vehicle (likely only from special agency vehicles). 5. Status of snowplow blade (up/down) (likely only from special agency vehicles).	Vehicle-to-TMS data transfer includes the following: 1. Broadcast windshield wiper status, traction control status, braking status, air temperature, air pressure. 2. ABS engagement status. 3. Road surface data (likely only from special agency vehicles). 4. Winter-maintenance materials output by vehicle (likely only from special agency vehicles). 5. Status of snowplow blade (up/down) (likely only from special agency vehicles).	Vehicle-to-TMS data transfer includes the following: 1. Broadcast windshield wiper status, traction control status, braking status, air temperature, air pressure. 2. ABS engagement status. 3. Road surface data (likely only from special agency vehicles). 4. Winter-maintenance materials output by vehicle (likely only from special agency vehicles). 5. Status of snowplow blade (up/down) (likely only from special agency vehicles).	Vehicle-to-TMS data transfer includes the following: 1. Broadcast windshield wiper status, traction control status, braking status, air temperature, air pressure. 2. ABS engagement status. 3. Road surface data (likely only from special agency vehicles). 4. Winter-maintenance materials output by vehicle (likely only from special agency vehicles). 5. Status of snowplow blade (up/down) (likely only from special agency vehicles).
Detect	B	TMS-to-vehicle data transfer includes the following: No additional activity under this operational action.	TMS-to-vehicle data transfer includes the following: No additional activity under this operational action.	TMS-to-vehicle data transfer includes the following: No additional activity under this operational action.	TMS-to-vehicle data transfer includes the following: No additional activity under this operational action.	TMS-to-vehicle data transfer includes the following: No additional activity under this operational action.	TMS-to-vehicle data transfer includes the following: No additional activity under this operational action.
Detect	B	Vehicle-to-TMS data transfer includes the following: No additional activity under this operational action.	Vehicle-to-TMS data transfer includes the following: No additional activity under this operational action.	Vehicle-to-TMS data transfer includes the following: No additional activity under this operational action.	Vehicle-to-TMS data transfer includes the following: No additional activity under this operational action.	Vehicle-to-TMS data transfer includes the following: No additional activity under this operational action.	Vehicle-to-TMS data transfer includes the following: No additional activity under this operational action.
Detect	B	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.
Detect	C	TMS-to-vehicle data transfer includes the following: No additional activity under this operational action.	TMS-to-vehicle data transfer includes the following: No additional activity under this operational action.	TMS-to-vehicle data transfer includes the following: No additional activity under this operational action.	TMS-to-vehicle data transfer includes the following: No additional activity under this operational action.	TMS-to-vehicle data transfer includes the following: No additional activity under this operational action.	TMS-to-vehicle data transfer includes the following: No additional activity under this operational action.

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Detect	C	Vehicle-to-TMS data transfer includes the following: No additional activity under this operational action.	Vehicle-to-TMS data transfer includes the following: No additional activity under this operational action.	Vehicle-to-TMS data transfer includes the following: No additional activity under this operational action.	Vehicle-to-TMS data transfer includes the following: No additional activity under this operational action.	Vehicle-to-TMS data transfer includes the following: No additional activity under this operational action.	Vehicle-to-TMS data transfer includes the following: No additional activity under this operational action.
Detect	C	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.
Notify and advise	No cooperative automation	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.
Notify and advise	A	TMS internal data transfer includes the following: 1. Broadcast weather data from third-party providers (NWS and others). 2. Broadcast weather data from RWIS stations. 3. Use agency fleet data and obtained weather data in Maintenance Decision Support System.	TMS internal data transfer includes the following: 1. Broadcast weather data from third-party providers (NWS and others). 2. Broadcast weather data from RWIS stations. 3. Use agency fleet data and obtained weather data in Maintenance Decision Support System.	TMS internal data transfer includes the following: 1. Broadcast weather data from third-party providers (NWS and others). 2. Broadcast weather data from RWIS stations. 3. Use agency fleet data and obtained weather data in Maintenance Decision Support System.	TMS internal data transfer includes the following: 1. Broadcast weather data from third-party providers (NWS and others). 2. Broadcast weather data from RWIS stations. 3. Use agency fleet data and obtained weather data in Maintenance Decision Support System.	TMS internal data transfer includes the following: 1. Broadcast weather data from third-party providers (NWS and others). 2. Broadcast weather data from RWIS stations. 3. Use agency fleet data and obtained weather data in Maintenance Decision Support System.	TMS internal data transfer includes the following: 1. Broadcast weather data from third-party providers (NWS and others). 2. Broadcast weather data from RWIS stations. 3. Use agency fleet data and obtained weather data in Maintenance Decision Support System.
Notify and advise	A	TMS-to-vehicle data transfer includes the following: 1. Broadcast road weather advisories. 2. Send road/lane closure data. 3. Broadcast reduced speed data. 4. Broadcast virtual DMS data.	TMS-to-vehicle data transfer includes the following: 1. Broadcast road weather advisories. 2. Send road/lane closure data. 3. Broadcast reduced speed data. 4. Broadcast virtual DMS data.	TMS-to-vehicle data transfer includes the following: 1. Broadcast road weather advisories. 2. Send road/lane closure data. 3. Broadcast reduced speed data. 4. Broadcast virtual DMS data.	TMS-to-vehicle data transfer includes the following: 1. Broadcast road weather advisories. 2. Send road/lane closure data. 3. Broadcast reduced speed data. 4. Broadcast virtual DMS data.	TMS-to-vehicle data transfer includes the following: 1. Broadcast road weather advisories. 2. Send road/lane closure data. 3. Broadcast reduced speed data. 4. Broadcast virtual DMS data.	TMS-to-vehicle data transfer includes the following: 1. Broadcast road weather advisories. 2. Send road/lane closure data. 3. Broadcast reduced speed data. 4. Broadcast virtual DMS data.

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Notify and advise	A	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast vehicle location, speed, and heading data (traffic-situation data and vehicle-situation data). 2. Broadcast vehicle environmental data (vehicle environmental data).(6) 3. Broadcast raw and/or processed reported vehicle speeds and other vehicle data (traffic-situation data). Counts and other derived values across vehicles are aggregated outside of the reporting vehicle. 4. Broadcast location in three dimensions, heading, speed, acceleration, braking status, and size (vehicle location and motion for surveillance).(7)	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast vehicle location, speed, and heading data (traffic-situation data and vehicle-situation data). 2. Broadcast vehicle environmental data (vehicle environmental data).(6) 3. Broadcast raw and/or processed reported vehicle speeds and other vehicle data (traffic-situation data). Counts and other derived values across vehicles are aggregated outside of the reporting vehicle. 4. Broadcast location in three dimensions, heading, speed, acceleration, braking status, and size (vehicle location and motion for surveillance).(7)	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast vehicle location, speed, and heading data (traffic-situation data and vehicle-situation data). 2. Broadcast vehicle environmental data (vehicle environmental data).(6) 3. Broadcast raw and/or processed reported vehicle speeds and other vehicle data (traffic-situation data). Counts and other derived values across vehicles are aggregated outside of the reporting vehicle. 4. Broadcast location in three dimensions, heading, speed, acceleration, braking status, and size (vehicle location and motion for surveillance).(7)	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast vehicle location, speed, and heading data (traffic-situation data and vehicle-situation data). 2. Broadcast vehicle environmental data (vehicle environmental data).(6) 3. Broadcast raw and/or processed reported vehicle speeds and other vehicle data (traffic-situation data). Counts and other derived values across vehicles are aggregated outside of the reporting vehicle. 4. Broadcast location in three dimensions, heading, speed, acceleration, braking status, and size (vehicle location and motion for surveillance).(7)	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast vehicle location, speed, and heading data (traffic-situation data and vehicle-situation data). 2. Broadcast vehicle environmental data (vehicle environmental data).(6) 3. Broadcast raw and/or processed reported vehicle speeds and other vehicle data (traffic-situation data). Counts and other derived values across vehicles are aggregated outside of the reporting vehicle. 4. Broadcast location in three dimensions, heading, speed, acceleration, braking status, and size (vehicle location and motion for surveillance).(7)	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast vehicle location, speed, and heading data (traffic-situation data and vehicle-situation data). 2. Broadcast vehicle environmental data (vehicle environmental data).(6) 3. Broadcast raw and/or processed reported vehicle speeds and other vehicle data (traffic-situation data). Counts and other derived values across vehicles are aggregated outside of the reporting vehicle. 4. Broadcast location in three dimensions, heading, speed, acceleration, braking status, and size (vehicle location and motion for surveillance).(7)
Notify and advise	A	Vehicle-to-vehicle data transfer includes the following: If a vehicle receives weather, roadway, or traffic condition notifications from another vehicle or TMS, it judiciously rebroadcasts this information to provide early warning to other approaching vehicles farther upstream (judgment involves limited distance upstream and limited frequency, based on activity of rebroadcasts from other vehicles): 1. Broadcast status data about driving mode adjustments by a vehicle in response to weather conditions, such as avoiding black ice. 2. Broadcast status data about driving mode adjustments by road weather-response vehicles to other equipped vehicles.	V2V data transfer includes the following: If a vehicle receives weather, roadway, or traffic condition notifications from another vehicle or TMS, it judiciously rebroadcasts this information to provide early warning to other approaching vehicles farther upstream (judgment involves limited distance upstream and limited frequency, based on activity of rebroadcasts from other vehicles): 1. Broadcast status data about driving mode adjustments by a vehicle in response to weather conditions, such as avoiding black ice. 2. Broadcast status data about driving mode adjustments by road weather-response vehicles to other equipped vehicles.	V2V data transfer includes the following: If a vehicle receives weather, roadway, or traffic condition notifications from another vehicle or TMS, it judiciously rebroadcasts this information to provide early warning to other approaching vehicles farther upstream (judgment involves limited distance upstream and limited frequency, based on activity of rebroadcasts from other vehicles): 1. Broadcast status data about driving mode adjustments by a vehicle in response to weather conditions, such as avoiding black ice. 2. Broadcast status data about driving mode adjustments by road weather-response vehicles to other equipped vehicles.	V2V data transfer includes the following: If a vehicle receives weather, roadway, or traffic condition notifications from another vehicle or TMS, it judiciously rebroadcasts this information to provide early warning to other approaching vehicles farther upstream (judgment involves limited distance upstream and limited frequency, based on activity of rebroadcasts from other vehicles): 1. Broadcast status data about driving mode adjustments by a vehicle in response to weather conditions, such as avoiding black ice. 2. Broadcast status data about driving mode adjustments by road weather-response vehicles to other equipped vehicles.	V2V data transfer includes the following: If a vehicle receives weather, roadway, or traffic condition notifications from another vehicle or TMS, it judiciously rebroadcasts this information to provide early warning to other approaching vehicles farther upstream (judgment involves limited distance upstream and limited frequency, based on activity of rebroadcasts from other vehicles): 1. Broadcast status data about driving mode adjustments by a vehicle in response to weather conditions, such as avoiding black ice. 2. Broadcast status data about driving mode adjustments by road weather-response vehicles to other equipped vehicles.	V2V data transfer includes the following: If a vehicle receives weather, roadway, or traffic condition notifications from another vehicle or TMS, it judiciously rebroadcasts this information to provide early warning to other approaching vehicles farther upstream (judgment involves limited distance upstream and limited frequency, based on activity of rebroadcasts from other vehicles): 1. Broadcast status data about driving mode adjustments by a vehicle in response to weather conditions, such as avoiding black ice. 2. Broadcast status data about driving mode adjustments by road weather-response vehicles to other equipped vehicles.
Notify and advise	B	TMS-to-vehicle data transfer includes the following: In addition to Class A, broadcast road weather forecasts specific for geofenced areas.	TMS-to-vehicle data transfer includes the following: In addition to Class A, broadcast road weather forecasts specific for geofenced areas.	TMS-to-vehicle data transfer includes the following: In addition to Class A, broadcast road weather forecasts specific for geofenced areas.	TMS-to-vehicle data transfer includes the following: In addition to Class A, broadcast road weather forecasts specific for geofenced areas.	TMS-to-vehicle data transfer includes the following: In addition to Class A, broadcast road weather forecasts specific for geofenced areas.	TMS-to-vehicle data transfer includes the following: In addition to Class A, broadcast road weather forecasts specific for geofenced areas.
Notify and advise	B	Vehicle-to-TMS data transfer includes the following: In addition to Class A, broadcast vehicle path predictions, including intention of following detour or stoppage advisories.	Vehicle-to-TMS data transfer includes the following: In addition to Class A, broadcast vehicle path predictions, including intention of following detour or stoppage advisories.	Vehicle-to-TMS data transfer includes the following: In addition to Class A, broadcast vehicle path predictions, including intention of following detour or stoppage advisories.	Vehicle-to-TMS data transfer includes the following: In addition to Class A, broadcast vehicle path predictions, including intention of following detour or stoppage advisories.	Vehicle-to-TMS data transfer includes the following: In addition to Class A, broadcast vehicle path predictions, including intention of following detour or stoppage advisories.	Vehicle-to-TMS data transfer includes the following: In addition to Class A, broadcast vehicle path predictions, including intention of following detour or stoppage advisories.

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Notify and advise	B	V2V data transfer includes the following in addition to Class A: 1. Broadcast intentional data about driving mode adjustments about to be undertaken by a vehicle in response to weather conditions, such as avoiding black ice. 2. Broadcast intentional data about driving mode adjustments about to be undertaken by road weather-response vehicles to other equipped vehicles.	V2V data transfer includes the following in addition to Class A: 1. Broadcast intentional data about driving mode adjustments about to be undertaken by a vehicle in response to weather conditions, such as avoiding black ice. 2. Broadcast intentional data about driving mode adjustments about to be undertaken by road weather-response vehicles to other equipped vehicles.	V2V data transfer includes the following in addition to Class A: 1. Broadcast intentional data about driving mode adjustments about to be undertaken by a vehicle in response to weather conditions, such as avoiding black ice. 2. Broadcast intentional data about driving mode adjustments about to be undertaken by road weather-response vehicles to other equipped vehicles.	V2V data transfer includes the following in addition to Class A: 1. Broadcast intentional data about driving mode adjustments about to be undertaken by a vehicle in response to weather conditions, such as avoiding black ice. 2. Broadcast intentional data about driving mode adjustments about to be undertaken by road weather-response vehicles to other equipped vehicles.	V2V data transfer includes the following in addition to Class A: 1. Broadcast intentional data about driving mode adjustments about to be undertaken by a vehicle in response to weather conditions, such as avoiding black ice. 2. Broadcast intentional data about driving mode adjustments about to be undertaken by road weather-response vehicles to other equipped vehicles.	V2V data transfer includes the following in addition to Class A: 1. Broadcast intentional data about driving mode adjustments about to be undertaken by a vehicle in response to weather conditions, such as avoiding black ice. 2. Broadcast intentional data about driving mode adjustments about to be undertaken by road weather-response vehicles to other equipped vehicles.
Notify and advise	C	TMS-to-vehicle data transfer includes the following: No additional activity under this operational action.	TMS-to-vehicle data transfer includes the following: No additional activity under this operational action.	TMS-to-vehicle data transfer includes the following: No additional activity under this operational action.	TMS-to-vehicle data transfer includes the following: No additional activity under this operational action.	TMS-to-vehicle data transfer includes the following: No additional activity under this operational action.	TMS-to-vehicle data transfer includes the following: No additional activity under this operational action.
Notify and advise	C	Vehicle-to-TMS data transfer includes the following: No additional activity under this operational action.	Vehicle-to-TMS data transfer includes the following: No additional activity under this operational action.	Vehicle-to-TMS data transfer includes the following: No additional activity under this operational action.	Vehicle-to-TMS data transfer includes the following: No additional activity under this operational action.	Vehicle-to-TMS data transfer includes the following: No additional activity under this operational action.	Vehicle-to-TMS data transfer includes the following: No additional activity under this operational action.
Notify and advise	C	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.
Control	No cooperative automation	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.
Control	A	TMS internal data transfer includes the following: Using preestablished SOPs, weather-response vehicles are notified to broadcast their vehicle data.	TMS internal data transfer includes the following: Using preestablished SOPs, weather-response vehicles are notified to broadcast their vehicle data.	TMS internal data transfer includes the following: Using preestablished SOPs, weather-response vehicles are notified to broadcast their vehicle data.	TMS internal data transfer includes the following: Using preestablished SOPs, weather-response vehicles are notified to broadcast their vehicle data.	TMS internal data transfer includes the following: Using preestablished SOPs, weather-response vehicles are notified to broadcast their vehicle data.	TMS internal data transfer includes the following Using preestablished SOPs, weather-response vehicles are notified to broadcast their vehicle data.

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Control	A	TMS-to-vehicle data transfer includes the following: 1. Broadcast lane usage regulations. 2. Broadcast closure of hazardous roads and bridges. 3. Broadcast roadway access restrictions (e.g., size, height, weight, and profile restrictions) and/or requirements (e.g., tire chains/alternate traction devices) for all vehicle types or for particular vehicle types. 4. Broadcast VSLs for all vehicle types or for particular vehicle types. 5. Broadcast adjustments to ramp-metering rates. 6. Broadcast adjustments or modifications to traffic signals, including signal phasing and timing, clearance interval durations. 7. Broadcast VSLs received from VSL sign (all vehicle types). 8. Broadcast pavement condition information (likely only from special agency vehicles). 9. Broadcast parking restrictions. 10. Broadcast reversible lane operations status.	TMS-to-vehicle data transfer includes the following: 1. Broadcast lane usage regulations. 2. Broadcast closure of hazardous roads and bridges. 3. Broadcast roadway access restrictions (e.g., size, height, weight, and profile restrictions) and/or requirements (e.g., tire chains/alternate traction devices) for all vehicle types or for particular vehicle types. 4. Broadcast VSLs for all vehicle types or for particular vehicle types. 5. Broadcast adjustments to ramp-metering rates. 6. Broadcast adjustments or modifications to traffic signals, including signal phasing and timing, clearance interval durations. 7. Broadcast VSLs received from VSL sign (all vehicle types). 8. Broadcast pavement condition information (likely only from special agency vehicles). 9. Broadcast parking restrictions. 10. Broadcast reversible lane operations status.	TMS-to-vehicle data transfer includes the following: 1. Broadcast lane usage regulations. 2. Broadcast closure of hazardous roads and bridges. 3. Broadcast roadway access restrictions (e.g., size, height, weight, and profile restrictions) and/or requirements (e.g., tire chains/alternate traction devices) for all vehicle types or for particular vehicle types. 4. Broadcast VSLs for all vehicle types or for particular vehicle types. 5. Broadcast adjustments to ramp-metering rates. 6. Broadcast adjustments or modifications to traffic signals, including signal phasing and timing, clearance interval durations. 7. Broadcast VSLs received from VSL sign (all vehicle types). 8. Broadcast pavement condition information (likely only from special agency vehicles). 9. Broadcast parking restrictions. 10. Broadcast reversible lane operations status.	TMS-to-vehicle data transfer includes the following: 1. Broadcast lane usage regulations. 2. Broadcast closure of hazardous roads and bridges. 3. Broadcast roadway access restrictions (e.g., size, height, weight, and profile restrictions) and/or requirements (e.g., tire chains/alternate traction devices) for all vehicle types or for particular vehicle types. 4. Broadcast VSLs for all vehicle types or for particular vehicle types. 5. Broadcast adjustments to ramp-metering rates. 6. Broadcast adjustments or modifications to traffic signals, including signal phasing and timing, clearance interval durations. 7. Broadcast VSLs received from VSL sign (all vehicle types). 8. Broadcast pavement condition information (likely only from special agency vehicles). 9. Broadcast parking restrictions. 10. Broadcast reversible lane operations status.	TMS-to-vehicle data transfer includes the following: 1. Broadcast lane usage regulations. 2. Broadcast closure of hazardous roads and bridges. 3. Broadcast roadway access restrictions (e.g., size, height, weight, and profile restrictions) and/or requirements (e.g., tire chains/alternate traction devices) for all vehicle types or for particular vehicle types. 4. Broadcast VSLs for all vehicle types or for particular vehicle types. 5. Broadcast adjustments to ramp-metering rates. 6. Broadcast adjustments or modifications to traffic signals, including signal phasing and timing, clearance interval durations. 7. Broadcast VSLs received from VSL sign (all vehicle types). 8. Broadcast pavement condition information (likely only from special agency vehicles). 9. Broadcast parking restrictions. 10. Broadcast reversible lane operations status.	TMS-to-vehicle data transfer includes the following: 1. Broadcast lane usage regulations. 2. Broadcast closure of hazardous roads and bridges. 3. Broadcast roadway access restrictions (e.g., size, height, weight, and profile restrictions) and/or requirements (e.g., tire chains/alternate traction devices) for all vehicle types or for particular vehicle types. 4. Broadcast VSLs for all vehicle types or for particular vehicle types. 5. Broadcast adjustments to ramp-metering rates. 6. Broadcast adjustments or modifications to traffic signals, including signal phasing and timing, clearance interval durations. 7. Broadcast VSLs received from VSL sign (all vehicle types). 8. Broadcast pavement condition information (likely only from special agency vehicles). 9. Broadcast parking restrictions. 10. Broadcast reversible lane operations status.
Control	A	Vehicle-to-TMS data transfer includes the following: 1. Broadcast location, speed, heading (all vehicle types). 2. Broadcast any onboard equipment failures, such as brakes, spreaders, plows, mowing equipment (likely only from special agency vehicles). 3. Broadcast vehicle environmental data (all vehicle types).	Vehicle-to-TMS data transfer includes the following: 1. Broadcast location, speed, heading (all vehicle types). 2. Broadcast any onboard equipment failures, such as brakes, spreaders, plows, mowing equipment (likely only from special agency vehicles). 3. Broadcast vehicle environmental data (all vehicle types).	Vehicle-to-TMS data transfer includes the following: 1. Broadcast location, speed, heading (all vehicle types). 2. Broadcast any onboard equipment failures, such as brakes, spreaders, plows, mowing equipment (likely only from special agency vehicles). 3. Broadcast vehicle environmental data (all vehicle types).	Vehicle-to-TMS data transfer includes the following: 1. Broadcast location, speed, heading (all vehicle types). 2. Broadcast any onboard equipment failures, such as brakes, spreaders, plows, mowing equipment (likely only from special agency vehicles). 3. Broadcast vehicle environmental data (all vehicle types).	Vehicle-to-TMS data transfer includes the following: 1. Broadcast location, speed, heading (all vehicle types). 2. Broadcast any onboard equipment failures, such as brakes, spreaders, plows, mowing equipment (likely only from special agency vehicles). 3. Broadcast vehicle environmental data (all vehicle types).	Vehicle-to-TMS data transfer includes the following: 1. Broadcast location, speed, heading (all vehicle types). 2. Broadcast any onboard equipment failures, such as brakes, spreaders, plows, mowing equipment (likely only from special agency vehicles). 3. Broadcast vehicle environmental data (all vehicle types).
Control	A	V2V data transfer includes the following: Continuously broadcast location data, speeds, headings, and other vehicle data, such as vehicle-detected environment-related information and provide any changes to other vehicles (for both weather-response vehicles and other vehicles).	V2V data transfer includes the following: Continuously broadcast location data, speeds, headings, and other vehicle data, such as vehicle-detected environment-related information and provide any changes to other vehicles (for both weather-response vehicles and other vehicles).	V2V data transfer includes the following: Continuously broadcast location data, speeds, headings, and other vehicle data, such as vehicle-detected environment-related information and provide any changes to other vehicles (for both weather-response vehicles and other vehicles).	V2V data transfer includes the following: Continuously broadcast location data, speeds, headings, and other vehicle data, such as vehicle-detected environment-related information and provide any changes to other vehicles (for both weather-response vehicles and other vehicles).	V2V data transfer includes the following: Continuously broadcast location data, speeds, headings, and other vehicle data, such as vehicle-detected environment-related information and provide any changes to other vehicles (for both weather-response vehicles and other vehicles).	V2V data transfer includes the following: Continuously broadcast location data, speeds, headings, and other vehicle data, such as vehicle-detected environment-related information and provide any changes to other vehicles (for both weather-response vehicles and other vehicles).

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Control	B	TMS-to-vehicle data transfer includes the following in addition to Class A: Broadcast forecasted and anticipated changes to the status data (see above) based on road weather and traffic condition forecasting models and simulations.	TMS-to-vehicle data transfer includes the following in addition to Class A: Broadcast forecasted and anticipated changes to the status data (see above) based on road weather and traffic condition forecasting models and simulations.	TMS-to-vehicle data transfer includes the following in addition to Class A and Level 0 through Level 1: 1. Broadcast curve speed warnings. 2. Broadcast rollover warnings. 3. Broadcast stop sign violation warnings.	TMS-to-vehicle data transfer includes the following: In addition to Class A and Level 0 through Level 1, broadcast command for drivers to assume control at geofenced areas where severe environmental impacts are encountered.	TMS-to-vehicle data transfer includes the following: In addition to Class A and Level 0 through Level 2, broadcast environmental data within highly geofenced areas.	TMS-to-vehicle data transfer includes the following: In addition to Class A and Level 0 through Level 2, broadcast environmental data within highly geofenced areas.
Control	B	Vehicle-to-TMS data transfer includes the following: No activity under this operational action.	Vehicle-to-TMS data transfer includes the following: No activity under this operational action.	Vehicle-to-TMS data transfer includes the following in addition to Class A: 1. Broadcast any onboard equipment failures, such as brakes, spreaders, plows, mowing equipment (fleet vehicles). 2. Broadcast vehicle environmental data (all vehicle types).	Vehicle-to-TMS data transfer includes the following in addition to Class A: 1. Broadcast any onboard equipment failures, such as brakes, spreaders, plows, mowing equipment (fleet vehicles). 2. Broadcast vehicle environmental data (all vehicle types).	Vehicle-to-TMS data transfer includes the following in addition to Class A: 1. Broadcast any onboard equipment failures, such as brakes, spreaders, plows, mowing equipment (fleet vehicles). 2. Broadcast vehicle environmental data (all vehicle types).	Vehicle-to-TMS data transfer includes the following in addition to Class A: 1. Broadcast any onboard equipment failures, such as brakes, spreaders, plows, mowing equipment (fleet vehicles). 2. Broadcast vehicle environmental data (all vehicle types).
Control	B	V2V data transfer includes the following in addition to Class A: Receive trajectory data from neighboring vehicles and weather-response vehicles. This information can be displayed to the human operator to aid in decision making about creating adequate right-of-way for snowplows and other weather-response equipment.	V2V data transfer includes the following in addition to Class A: Receive trajectory data from neighboring vehicles and weather-response vehicles. This information can be displayed to the human operator to aid in decision making about creating adequate right-of-way for snowplows and other weather-response equipment.	V2V data transfer includes the following in addition to Class A and Level 0 through Level 1: 1. Weather-response vehicles broadcast their intended trajectories as they approach the scene, which will be dependent upon their receipt of trajectory plans from other Class B or higher vehicles in the vicinity. 2. Vehicles in vicinity observe weather-response vehicles' intended trajectories, plan their own trajectories to clear a path, and broadcast these plans for other vehicles' awareness.	V2V data transfer includes the following in addition to Class A and Level 0 through Level 1: 1. Weather-response vehicles broadcast their intended trajectories as they approach the scene, which will be dependent upon their receipt of trajectory plans from other Class B or higher vehicles in the vicinity. 2. Vehicles in vicinity observe weather-response vehicles' intended trajectories, plan their own trajectories to clear a path, and broadcast these plans for other vehicles' awareness.	V2V data transfer includes the following in addition to Class A and Level 0 through Level 1: 1. Weather-response vehicles broadcast their intended trajectories as they approach the scene, which will be dependent upon their receipt of trajectory plans from other Class B or higher vehicles in the vicinity. 2. Vehicles in vicinity observe weather-response vehicles' intended trajectories, plan their own trajectories to clear a path, and broadcast these plans for other vehicles' awareness.	V2V data transfer includes the following in addition to Class A and Level 0 through Level 1: 1. Weather-response vehicles broadcast their intended trajectories as they approach the scene, which will be dependent upon their receipt of trajectory plans from other Class B or higher vehicles in the vicinity. 2. Vehicles in vicinity observe weather-response vehicles' intended trajectories, plan their own trajectories to clear a path, and broadcast these plans for other vehicles' awareness.
Control	C	TMS-to-vehicle data transfer includes the following: No activity under this operational action.	TMS-to-vehicle data transfer includes the following: No activity under this operational action.	TMS-to-vehicle data transfer includes the following: No activity under this operational action.	TMS-to-vehicle data transfer includes the following: No activity under this operational action.	TMS-to-vehicle data transfer includes the following: No activity under this operational action.	TMS-to-vehicle data transfer includes the following: No activity under this operational action.
Control	C	Vehicle-to-TMS data transfer includes the following: No activity under this operational action.	Vehicle-to-TMS data transfer includes the following: No activity under this operational action.	Vehicle-to-TMS data transfer includes the following: No activity under this operational action.	Vehicle-to-TMS data transfer includes the following: No activity under this operational action.	Vehicle-to-TMS data transfer includes the following: No activity under this operational action.	Vehicle-to-TMS data transfer includes the following: No activity under this operational action.

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Control	C	V2V data transfer includes the following: No activity under this operational action.	V2V data transfer includes the following: No activity under this operational action.	V2V data transfer includes the following: In addition to the Class B: 1. Weather-response vehicles actively negotiate with each other to determine a coordinated approach and configuration for the weather condition clearance areas, assuming that other vehicles will yield to them. 2. Vehicles negotiate with each other to cooperatively change lanes, speeds, platooning parameters, and so on, as necessary to navigate the weather-affected area according to the temporary rules set up by the deployed geofences and travel direction.	V2V data transfer includes the following: In addition to the Class B: 1. Weather-response vehicles actively negotiate with each other to determine a coordinated approach and configuration for the weather condition clearance areas, assuming that other vehicles will yield to them. 2. Vehicles negotiate with each other to cooperatively change lanes, speeds, platooning parameters, and so on, as necessary to navigate the weather-affected area according to the temporary rules set up by the deployed geofences and travel direction.	V2V data transfer includes the following: In addition to the Class B: 1. Weather-response vehicles actively negotiate with each other to determine a coordinated approach and configuration for the weather condition clearance areas, assuming that other vehicles will yield to them. 2. Vehicles negotiate with each other to cooperatively change lanes, speeds, platooning parameters, and so on, as necessary to navigate the weather-affected area according to the temporary rules set up by the deployed geofences and travel direction.	V2V data transfer includes the following: In addition to the Class B: 1. Weather-response vehicles actively negotiate with each other to determine a coordinated approach and configuration for the weather condition clearance areas, assuming that other vehicles will yield to them. 2. Vehicles negotiate with each other to cooperatively change lanes, speeds, platooning parameters, and so on, as necessary to navigate the weather-affected area according to the temporary rules set up by the deployed geofences and travel direction.
Treat and maintain	No cooperative automation	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.
Treat and maintain	A	TMS internal data transfer includes the following: Using preestablished SOPs, weather-response vehicles are notified to broadcast their vehicle locations and treatment application data, including routes of treatment and sequence.	TMS internal data transfer includes the following: Using preestablished SOPs, weather-response vehicles are notified to broadcast their vehicle locations and treatment application data, including routes of treatment and sequence.	TMS internal data transfer includes the following: Using preestablished SOPs, weather-response vehicles are notified to broadcast their vehicle locations and treatment application data, including routes of treatment and sequence.	TMS internal data transfer includes the following: Using preestablished SOPs, weather-response vehicles are notified to broadcast their vehicle locations and treatment application data, including routes of treatment and sequence.	TMS internal data transfer includes the following: Using preestablished SOPs, weather-response vehicles are notified to broadcast their vehicle locations and treatment application data, including routes of treatment and sequence.	TMS internal data transfer includes the following: Using preestablished SOPs, weather-response vehicles are notified to broadcast their vehicle locations and treatment application data, including routes of treatment and sequence.
Treat and maintain	A	TMS-to-vehicle data transfer includes the following: Broadcast road-treatment data (e.g., chemicals, sand, and plowing locations) for specific locations (likely only from special agency vehicles).	TMS-to-vehicle data transfer includes the following: Broadcast road-treatment data (e.g., chemicals, sand, and plowing locations) for specific locations (likely only from special agency vehicles).	TMS-to-vehicle data transfer includes the following: Broadcast road-treatment data (e.g., chemicals, sand, and plowing locations) for specific locations (likely only from special agency vehicles).	TMS-to-vehicle data transfer includes the following: Broadcast road-treatment data (e.g., chemicals, sand, and plowing locations) for specific locations (likely only from special agency vehicles).	TMS-to-vehicle data transfer includes the following: Broadcast road-treatment data (e.g., chemicals, sand, and plowing locations) for specific locations (likely only from special agency vehicles).	TMS-to-vehicle data transfer includes the following: Broadcast road-treatment data (e.g., chemicals, sand, and plowing locations) for specific locations (likely only from special agency vehicles).
Treat and maintain	A	Vehicle-to-TMS data transfer includes the following: 1. Broadcast location, speed, heading (all vehicle types). 2. Broadcast road treatment application performed, including date/time and location data (likely only from special agency vehicles).	Vehicle-to-TMS data transfer includes the following: 1. Broadcast location, speed, heading (all vehicle types). 2. Broadcast road treatment application performed, including date/time and location data (likely only from special agency vehicles).	Vehicle-to-TMS data transfer includes the following: 1. Broadcast location, speed, heading (all vehicle types). 2. Broadcast road treatment application performed, including date/time and location data (likely only from special agency vehicles).	Vehicle-to-TMS data transfer includes the following: 1. Broadcast location, speed, heading (all vehicle types). 2. Broadcast road treatment application performed, including date/time and location data (likely only from special agency vehicles).	Vehicle-to-TMS data transfer includes the following: 1. Broadcast location, speed, heading (all vehicle types). 2. Broadcast road treatment application performed, including date/time and location data (likely only from special agency vehicles).	Vehicle-to-TMS data transfer includes the following: 1. Broadcast location, speed, heading (all vehicle types). 2. Broadcast road treatment application performed, including date/time and location data (likely only from special agency vehicles).
Treat and maintain	A	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Treat and maintain	B	TMS-to-vehicle data transfer includes the following: In addition to Class A: 1. Send treatment routes and treatment data (e.g., mixture compositions) for the specific routes within geofences (likely only to special agency vehicles) and travel direction. 2. Broadcast road-treatment data (e.g., chemicals, sand, and plowing locations) for specific locations. 3. Broadcast queue warnings.	TMS-to-vehicle data transfer includes the following: In addition to Class A: 1. Send treatment routes and treatment data (e.g., mixture compositions) for the specific routes within geofences (likely only to special agency vehicles) and travel direction. 2. Broadcast road-treatment data (e.g., chemicals, sand, and plowing locations) for specific locations. 3. Broadcast queue warnings.	TMS-to-vehicle data transfer includes the following: In addition to Class A and Level 0 through Level 1, broadcast CACC (for all vehicles and for treatment vehicles operating in tandem).	TMS-to-vehicle data transfer includes the following: In addition to Class A and Level 0 through Level 2, broadcast command for drivers to assume control at geofenced areas and travel direction where treatment is to be applied.	TMS-to-vehicle data transfer includes the following: In addition to Class A and Level 0 through Level 1, broadcast command at geofenced areas and travel direction where treatment is to be applied.	TMS-to-vehicle data transfer includes the following: In addition to Class A and Level 0 through Level 1, roadcast command at geofenced areas and travel direction where treatment is to be applied.
Treat and maintain	B	Vehicle-to-TMS data transfer includes the following: In addition to Class A, broadcast road treatment application performed, including date/time and location data.	Vehicle-to-TMS data transfer includes the following: In addition to Class A, broadcast road treatment application performed, including date/time and location data.	Vehicle-to-TMS data transfer includes the following: In addition to Class A, broadcast road treatment application performed, including date/time and location data.	Vehicle-to-TMS data transfer includes the following: In addition to Class A, broadcast road treatment application performed, including date/time and location data.	Vehicle-to-TMS data transfer includes the following: In addition to Class A, broadcast road treatment application performed, including date/time and location data.	Vehicle-to-TMS data transfer includes the following: In addition to Class A, broadcast road treatment application performed, including date/time and location data.
Treat and maintain	B	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.
Treat and maintain	C	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.
Treat and maintain	C	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.
Treat and Maintain	C	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.

NOAA = National Oceanic and Atmospheric Administration; NWS = National Weather Service; RWIS = road weather information system; SOP = standard operating procedure; VSL = variable speed limit.

Framework for WZM Use Case

From a TMS operations perspective, table 41 shows the information a TMS can provide to CDA vehicles during work-zone activity, the information vehicles of different Automation Levels/Cooperation Classes can provide to a TMS during work-zone activity, and the information vehicles with different Automation Levels/Cooperation Classes can provide between one another during work-zone activity. This information includes both the data gathered by a TMS and data provided to the traveling public, State and local transit agencies, and third-party data users and providers. A TMS will continue to provide relevant data to drivers as it does now.

For WZM, the TSMO-focused TMS operations are defined by those activities that TMSs, and especially TMCs, typically perform when work zones are active. The operational actions associated with WZM are defined as follows:

- Notify and advise—performing activities in a structured manner to notify drivers and vehicles of the planned and active presence of a work zone within their travel direction.
- Respond—performing activities in a structured manner to address and resolve work-zone-related conditions.
- Manage site—performing activities on the roadside to address and resolve work-zone-related conditions.
- Manage traffic—performing activities to manage traffic approaching and affected by a work zone.
- Terminate—performing activities to resolve work-zone-related conditions, including field device actions and informing other affected TMSs, motorists, and the public.
- Recover—performing activities to return work-zone-related conditions to normal operations and reopen all lanes.

CDA-equipped vehicles encountering work zones can exchange data about the work zones detected by a vehicle and provide the information to other CDA-equipped vehicles. V2V operations can exchange data faster than a TMS between vehicles and follow procedures similar to the exchanges between TMSs and vehicles.

All content in table 41 is in addition to data determined by onboard sensing equipment that enable vehicles to detect, process, and react to obstacles and other vehicles and pedestrians in their path.

Table 41. Framework for TSMO within a CDA environment—WZM use case.

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Notify and advise	No cooperative automation	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.
Notify and advise	A	TMS-to-vehicle data transfer includes the following: 1. Provide work zone-related data pretrip or en route. En route data provided via 511, FM radio, highway advisory radio, or DMS to driver. 2. Broadcast information to partner agencies that need to be informed and/or involved in WZM. 3. Use machine learning and AI tools to create and execute work-zone notifications. 4. TMS broadcasts data, including geofence and direction, and details on the work zone, dynamic speed harmonization, and applicable detour information (different message contents for responder vehicles versus other vehicles). 5. Broadcast details on work zone layout, dynamic speed harmonization, and applicable detour information. 6. Broadcast queue warning. (Note this could also be processed and sent by RSU).[8]	TMS-to-vehicle data transfer includes the following: 1. Provide work zone-related data pretrip or en route. En route data provided via 511, FM radio, highway advisory radio, or DMS to driver. 2. Broadcast information to partner agencies that need to be informed and/or involved in WZM. 3. Use machine learning and AI tools to create and execute work-zone notifications. 4. TMS broadcasts data, including geofence and direction, and details on the work zone, dynamic speed harmonization, and applicable detour information (different message contents for responder vehicles versus other vehicles). 5. Broadcast details on work zone layout, dynamic speed harmonization, and applicable detour information. 6. Broadcast queue warning. (Note this could also be processed and sent by RSU).[8]	TMS-to-vehicle data transfer includes the following: 1. Provide work zone-related data pretrip or en route. En route data provided via 511, FM radio, highway advisory radio, or DMS to driver. 2. Broadcast information to partner agencies that need to be informed and/or involved in WZM. 3. Use machine learning and AI tools to create and execute work-zone notifications. 4. TMS broadcasts data, including geofence and direction, and details on the work zone, dynamic speed harmonization, and applicable detour information (different message contents for responder vehicles versus other vehicles). 5. Broadcast details on work zone layout, dynamic speed harmonization, and applicable detour information. 6. Broadcast queue warning. (Note this could also be processed and sent by RSU).[8]	TMS-to-vehicle data transfer includes the following: 1. Provide work zone-related data pretrip or en route. En route data provided via 511, FM radio, highway advisory radio, or DMS to driver. 2. Broadcast information to partner agencies that need to be informed and/or involved in WZM. 3. Use machine learning and AI tools to create and execute work-zone notifications. 4. TMS broadcasts data, including geofence and direction, and details on the work zone, dynamic speed harmonization, and applicable detour information (different message contents for responder vehicles versus other vehicles). 5. Broadcast details on work zone layout, dynamic speed harmonization, and applicable detour information. 6. Broadcast queue warning. (Note this could also be processed and sent by RSU).[8]	TMS-to-vehicle data transfer includes the following: 1. Provide work zone-related data pretrip or en route. En route data provided via 511, FM radio, highway advisory radio, or DMS to driver. 2. Broadcast information to partner agencies that need to be informed and/or involved in WZM. 3. Use machine learning and AI tools to create and execute work-zone notifications. 4. TMS broadcasts data, including geofence and direction, and details on the work zone, dynamic speed harmonization, and applicable detour information (different message contents for responder vehicles versus other vehicles). 5. Broadcast details on work zone layout, dynamic speed harmonization, and applicable detour information. 6. Broadcast queue warning. (Note this could also be processed and sent by RSU).[8]	TMS-to-vehicle data transfer includes the following: 1. Provide work zone-related data pretrip or en route. En route data provided via 511, FM radio, highway advisory radio, or DMS to driver. 2. Broadcast information to partner agencies that need to be informed and/or involved in WZM. 3. Use machine learning and AI tools to create and execute work-zone notifications. 4. TMS broadcasts data, including geofence and direction, and details on the work zone, dynamic speed harmonization, and applicable detour information (different message contents for responder vehicles versus other vehicles). 5. Broadcast details on work zone layout, dynamic speed harmonization, and applicable detour information. 6. Broadcast queue warning. (Note this could also be processed and sent by RSU).[8]
Notify and advise	A	V2V data transfer includes the following: If a vehicle receives a work-zone notification from another vehicle or TMS, it will judiciously rebroadcast this information to provide early warning to other approaching vehicles farther upstream (judgment involves limited distance upstream and limited frequency, based on activity of rebroadcasts from other vehicles).	V2V data transfer includes the following: If a vehicle receives a work-zone notification from another vehicle or TMS, it will judiciously rebroadcast this information to provide early warning to other approaching vehicles farther upstream (judgment involves limited distance upstream and limited frequency, based on activity of rebroadcasts from other vehicles).	V2V data transfer includes the following: If a vehicle receives a work-zone notification from another vehicle or TMS, it will judiciously rebroadcast this information to provide early warning to other approaching vehicles farther upstream (judgment involves limited distance upstream and limited frequency, based on activity of rebroadcasts from other vehicles).	V2V data transfer includes the following: If a vehicle receives a work-zone notification from another vehicle or TMS, it will judiciously rebroadcast this information to provide early warning to other approaching vehicles farther upstream (judgment involves limited distance upstream and limited frequency, based on activity of rebroadcasts from other vehicles).	V2V data transfer includes the following: If a vehicle receives a work-zone notification from another vehicle or TMS, it will judiciously rebroadcast this information to provide early warning to other approaching vehicles farther upstream (judgment involves limited distance upstream and limited frequency, based on activity of rebroadcasts from other vehicles).	V2V data transfer includes the following: If a vehicle receives a work-zone notification from another vehicle or TMS, it will judiciously rebroadcast this information to provide early warning to other approaching vehicles farther upstream (judgment involves limited distance upstream and limited frequency, based on activity of rebroadcasts from other vehicles).
Notify and advise	B	TMS-to-vehicle data transfer includes the following: There is no additional notify and advise activity for Class B vehicles.	TMS-to-vehicle data transfer includes the following: There is no additional notify and advise activity for Class B vehicles.	TMS-to-vehicle data transfer includes the following: There is no additional notify and advise activity for Class B vehicles.	TMS-to-vehicle data transfer includes the following: There is no additional notify and advise activity for Class B vehicles.	TMS-to-vehicle data transfer includes the following: There is no additional notify and advise activity for Class B vehicles.	TMS-to-vehicle data transfer includes the following: There is no additional notify and advise activity for Class B vehicles.

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Notify and advise	B	V2V data transfer includes the following: There is no additional notify and advise activity for Class B vehicles.	V2V data transfer includes the following: There is no additional notify and advise activity for Class B vehicles.	V2V data transfer includes the following: There is no additional notify and advise activity for Class B vehicles.	V2V data transfer includes the following: There is no additional notify and advise activity for Class B vehicles.	V2V data transfer includes the following: There is no additional notify and advise activity for Class B vehicles.	V2V data transfer includes the following: There is no additional notify and advise activity for Class B vehicles.
Notify and advise	C	TMS-to-vehicle data transfer includes the following: TMS sends notifications to vehicles that the network is being load balanced along with details of recommended detour route (generally applicable to Automation Levels 3 and higher only, but could theoretically apply to Level 0 through Level 2 vehicles).	TMS-to-vehicle data transfer includes the following: TMS sends notifications to vehicles that the network is being load balanced along with details of recommended detour route (generally applicable to Automation Levels 3 and higher only, but could theoretically apply to Level 0 through Level 2 vehicles).	TMS-to-vehicle data transfer includes the following: TMS sends notifications to vehicles that the network is being load balanced along with details of recommended detour route (generally applicable to Automation Levels 3 and higher only, but could theoretically apply to Level 0 through Level 2 vehicles).	TMS-to-vehicle data transfer includes the following: TMS sends notifications to vehicles that the network is being load balanced along with details of recommended detour route (generally applicable to Automation Levels 3 and higher only, but could theoretically apply to Level 0 through Level 2 vehicles).	TMS-to-vehicle data transfer includes the following: TMS sends notifications to vehicles that the network is being load balanced along with details of recommended detour route (generally applicable to Automation Levels 3 and higher only, but could theoretically apply to Level 0 through Level 2 vehicles).	TMS-to-vehicle data transfer includes the following: TMS sends notifications to vehicles that the network is being load balanced along with details of recommended detour route (generally applicable to Automation Levels 3 and higher only, but could theoretically apply to Level 0 through Level 2 vehicles).
Notify and advise	C	Vehicle-to-TMS data transfer includes the following: Vehicle sends acknowledgment of load-balancing instructions to TMS and response as to what route it intends to take (again, this is likely applicable to Automation Levels 3 and higher only, but could theoretically apply to Level 0 through Level 2 vehicles).	Vehicle-to-TMS data transfer includes the following: Vehicle sends acknowledgment of load-balancing instructions to TMS and response as to what route it intends to take (again, this is likely applicable to Automation Levels 3 and higher only, but could theoretically apply to Level 0 through Level 2 vehicles).	Vehicle-to-TMS data transfer includes the following: Vehicle sends acknowledgment of load-balancing instructions to TMS and response as to what route it intends to take (again, this is likely applicable to Automation Levels 3 and higher only, but could theoretically apply to Level 0 through Level 2 vehicles).	Vehicle-to-TMS data transfer includes the following: Vehicle sends acknowledgment of load-balancing instructions to TMS and response as to what route it intends to take (again, this is likely applicable to Automation Levels 3 and higher only, but could theoretically apply to Level 0 through Level 2 vehicles).	Vehicle-to-TMS data transfer includes the following: Vehicle sends acknowledgment of load-balancing instructions to TMS and response as to what route it intends to take (again, this is likely applicable to Automation Levels 3 and higher only, but could theoretically apply to Level 0 through Level 2 vehicles).	Vehicle-to-TMS data transfer includes the following: Vehicle sends acknowledgment of load-balancing instructions to TMS and response as to what route it intends to take (again, this is likely applicable to Automation Levels 3 and higher only, but could theoretically apply to Level 0 through Level 2 vehicles).
Notify and advise	C	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: In addition to Class A: If a vehicle is approaching a work zone, driver is instructed to assume vehicle control to manually negotiate lane merges as necessary to avoid the work zone and/or to redirect to detour route.	V2V data transfer includes the following: In addition to Class A: If a vehicle is approaching a work zone, driver is instructed to assume vehicle control to manually negotiate lane merges as necessary to avoid the work zone and/or to redirect to detour route.	V2V data transfer includes the following: In addition to Class A: If a vehicle is approaching a work zone, driver is instructed to assume vehicle control to manually negotiate lane merges as necessary to avoid the work zone and/or to redirect to detour route.
Respond	No cooperative automation	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.
Respond	A	TMS internal data transfer includes the following: Using preestablished SOPs, stage traffic management around work zone according to work zone layout, and manage work trucks in work zone.	TMS internal data transfer includes the following: Using preestablished SOPs, stage traffic management around work zone according to work zone layout, and manage work trucks in work zone.	TMS internal data transfer includes the following: Using preestablished SOPs, stage traffic management around work zone according to work zone layout, and manage work trucks in work zone.	TMS internal data transfer includes the following: Using preestablished SOPs, stage traffic management around work zone according to work zone layout, and manage work trucks in work zone.	TMS internal data transfer includes the following: Using preestablished SOPs, stage traffic management around work zone according to work zone layout, and manage work trucks in work zone.	TMS internal data transfer includes the following: Using preestablished SOPs, stage traffic management around work zone according to work zone layout, and manage work trucks in work zone.

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Respond	A	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast location data and speeds, providing any changes to the TMS (both passenger and work zone vehicles). 2. Broadcast other vehicle data, such as vehicle-detected environment-related information.	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast location data and speeds, providing any changes to the TMS (both passenger and work zone vehicles). 2. Broadcast other vehicle data, such as vehicle-detected environment-related information.	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast location data and speeds, providing any changes to the TMS (both passenger and work zone vehicles). 2. Broadcast other vehicle data, such as vehicle-detected environment-related information.	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast location data and speeds, providing any changes to the TMS (both passenger and work zone vehicles). 2. Broadcast other vehicle data, such as vehicle-detected environment-related information.	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast location data and speeds, providing any changes to the TMS (both passenger and work zone vehicles). 2. Broadcast other vehicle data, such as vehicle-detected environment-related information.	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast location data and speeds, providing any changes to the TMS (both passenger and work zone vehicles). 2. Broadcast other vehicle data, such as vehicle-detected environment-related information.
Respond	A	TMS-to-vehicle data transfer includes the following: 1. Broadcast geofence with a TMS-defined safe speed approaching work zone and/or to follow TMS-defined turn-by-turn detours to avoid the work zone. 2. Broadcast route guidance details (considering traffic conditions) to work zone vehicles.	TMS-to-vehicle data transfer includes the following: 1. Broadcast geofence with a TMS-defined safe speed approaching work zone and/or to follow TMS-defined turn-by-turn detours to avoid the work zone. 2. Broadcast route guidance details (considering traffic conditions) to work zone vehicles.	TMS-to-vehicle data transfer includes the following: 1. Broadcast geofence with a TMS-defined safe speed approaching work zone and/or to follow TMS-defined turn-by-turn detours to avoid the work zone. 2. Broadcast route guidance details (considering traffic conditions) to work zone vehicles.	TMS-to-vehicle data transfer includes the following: 1. Broadcast geofence with a TMS-defined safe speed approaching work zone and/or to follow TMS-defined turn-by-turn detours to avoid the work zone. 2. Broadcast route guidance details (considering traffic conditions) to work zone vehicles.	TMS-to-vehicle data transfer includes the following: 1. Broadcast geofence with a TMS-defined safe speed approaching work zone and/or to follow TMS-defined turn-by-turn detours to avoid the work zone. 2. Broadcast route guidance details (considering traffic conditions) to work zone vehicles.	TMS-to-vehicle data transfer includes the following: 1. Broadcast geofence with a TMS-defined safe speed approaching work zone and/or to follow TMS-defined turn-by-turn detours to avoid the work zone. 2. Broadcast route guidance details (considering traffic conditions) to work zone vehicles.
Respond	A	V2V data transfer includes the following: Continuously broadcast location data, speeds, headings, and other vehicle data, such as vehicle-detected environment-related information and provide any changes to other vehicles (for both vehicles and work zone vehicles).	V2V data transfer includes the following: Continuously broadcast location data, speeds, headings, and other vehicle data, such as vehicle-detected environment-related information and provide any changes to other vehicles (for both vehicles and work zone vehicles).	V2V data transfer includes the following: Continuously broadcast location data, speeds, headings, and other vehicle data, such as vehicle-detected environment-related information and provide any changes to other vehicles (for both vehicles and work zone vehicles).	V2V data transfer includes the following: Continuously broadcast location data, speeds, headings, and other vehicle data, such as vehicle-detected environment-related information and provide any changes to other vehicles (for both vehicles and work zone vehicles).	V2V data transfer includes the following: Continuously broadcast location data, speeds, headings, and other vehicle data, such as vehicle-detected environment-related information and provide any changes to other vehicles (for both vehicles and work zone vehicles).	V2V data transfer includes the following: Continuously broadcast location data, speeds, headings, and other vehicle data, such as vehicle-detected environment-related information and provide any changes to other vehicles (for both vehicles and work zone vehicles).
Respond	B	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: In addition to Class A and to the left (Levels 0 through 3): Broadcast suggestions to follow TMS-defined detours within geofenced areas, allowing for limited network load balancing.	TMS-to-vehicle data transfer includes the following: In addition to Class A and to the left (Levels 0 through 3): Broadcast suggestions to follow TMS-defined detours within geofenced areas, allowing for network load balancing for entire TMS coverage area.

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Respond	B	Vehicle-to-TMS data transfer includes the following: In addition to Class A, work zone vehicles at the work zone can better determine necessary traffic parameters than those parameters broadcast in the TMS geofence. In case the TMS does not yet have enough information to broadcast a geofence, a work zone vehicle may locally broadcast an in-field geofence devised by its operators, which could then be picked up and rebroadcast by the TMS.	Vehicle-to-TMS data transfer includes the following: In addition to Class A, work zone vehicles at the work zone can better determine necessary traffic parameters than those parameters broadcast in the TMS geofence. In case the TMS does not yet have enough information to broadcast a geofence, a work zone vehicle may locally broadcast an in-field geofence devised by its operators, which could then be picked up and rebroadcast by the TMS.	Vehicle-to-TMS data transfer includes the following: In addition to Class A, work zone vehicles at the work zone can better determine necessary traffic parameters than those parameters broadcast in the TMS geofence. In case the TMS does not yet have enough information to broadcast a geofence, a work zone vehicle may locally broadcast an in-field geofence devised by its operators, which could then be picked up and rebroadcast by the TMS.	Vehicle-to-TMS data transfer includes the following: In addition to Class A, work zone vehicles at the work zone can better determine necessary traffic parameters than those parameters broadcast in the TMS geofence. In case the TMS does not yet have enough information to broadcast a geofence, a work zone vehicle may locally broadcast an in-field geofence devised by its operators, which could then be picked up and rebroadcast by the TMS.	Vehicle-to-TMS data transfer includes the following: In addition to Class A, work zone vehicles at the work zone can better determine necessary traffic parameters than those parameters broadcast in the TMS geofence. In case the TMS does not yet have enough information to broadcast a geofence, a work zone vehicle may locally broadcast an in-field geofence devised by its operators, which could then be picked up and rebroadcast by the TMS.	Vehicle-to-TMS data transfer includes the following: In addition to Class A, work zone vehicles at the work zone can better determine necessary traffic parameters than those parameters broadcast in the TMS geofence. In case the TMS does not yet have enough information to broadcast a geofence, a work zone vehicle may locally broadcast an in-field geofence devised by its operators, which could then be picked up and rebroadcast by the TMS.
Respond	B	V2V data transfer includes the following: In addition to Class A, receive trajectory data from neighboring vehicles and work zone vehicles. This information can be displayed to the human operator to aid in decision making about how best to make room for work zone vehicles or, If a vehicle is a work zone vehicle, how to best navigate through other vehicles that may be attempting to make room.	V2V data transfer includes the following: In addition to Class A, receive trajectory data from neighboring vehicles and work zone vehicles. This information can be displayed to the human operator to aid in decision making about how best to make room for work zone vehicles or, If a vehicle is a work zone vehicle, how to best navigate through other vehicles that may be attempting to make room.	V2V data transfer includes the following in addition to Class A and Level 0 through Level 1: 1. Work zone vehicles broadcast their intended trajectories as they approach the work zone, which will be dependent upon their receipt of trajectory plans from other Class B or higher vehicles in the vicinity. 2. Vehicles in the vicinity observe work zone vehicles' intended trajectories, plan their own trajectories to clear a path, and broadcast these plans for other vehicles' awareness.	V2V data transfer includes the following in addition to Class A and Level 0 through Level 1: 1. Work zone vehicles broadcast their intended trajectories as they approach the work zone, which will be dependent upon their receipt of trajectory plans from other Class B or higher vehicles in the vicinity. 2. Vehicles in the vicinity observe work zone vehicles' intended trajectories, plan their own trajectories to clear a path, and broadcast these plans for other vehicles' awareness.	V2V data transfer includes the following in addition to Class A and Level 0 through Level 1: 1. Work zone vehicles broadcast their intended trajectories as they approach the work zone, which will be dependent upon their receipt of trajectory plans from other Class B or higher vehicles in the vicinity. 2. Vehicles in the vicinity observe work zone vehicles' intended trajectories, plan their own trajectories to clear a path, and broadcast these plans for other vehicles' awareness.	V2V data transfer includes the following in addition to Class A and Level 0 through Level 1: 1. Work zone vehicles broadcast their intended trajectories as they approach the work zone, which will be dependent upon their receipt of trajectory plans from other Class B or higher vehicles in the vicinity. 2. Vehicles in the vicinity observe work zone vehicles' intended trajectories, plan their own trajectories to clear a path, and broadcast these plans for other vehicles' awareness.
Respond	C	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.
Respond	C	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Respond	C	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following in addition to Class B: 1. Work zone vehicles actively negotiate with each other to determine a coordinated approach and configuration for the work zone; they make the assumption that other vehicles will yield to them. 2. Vehicles receive trajectory plans from work zone vehicles, and transmit acknowledgments that they respect work zone vehicles' priority and plan to clear a path. 3. Vehicles negotiate with each other to cooperate in changing lanes, speeds, platooning parameters, and so on, as necessary, to pass the work zone according to the temporary rules set up by the deployed geofences and the travel direction.	V2V data transfer includes the following: Same as Level 2 for this operational action.	V2V data transfer includes the following: Same as Level 2 for this operational action.	V2V data transfer includes the following: Same as Level 2 for this operational action.
Manage site	No cooperative automation	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.
Manage site	A	TMS internal data transfer includes the following: 1. Monitor status and performance field devices and location of field crew vehicles. 2. Accurately assess conditions at work zone.	TMS internal data transfer includes the following: 1. Monitor status and performance field devices and location of field crew vehicles. 2. Accurately assess conditions at work zone.	TMS internal data transfer includes the following: 1. Monitor status and performance field devices and location of field crew vehicles. 2. Accurately assess conditions at work zone.	TMS internal data transfer includes the following: 1. Monitor status and performance field devices and location of field crew vehicles. 2. Accurately assess conditions at work zone.	TMS internal data transfer includes the following: 1. Monitor status and performance field devices and location of field crew vehicles. 2. Accurately assess conditions at work zone.	TMS internal data transfer includes the following: 1. Monitor status and performance field devices and location of field crew vehicles. 2. Accurately assess conditions at work zone.
Manage site	A	TMS-to-vehicle data transfer includes the following: Continuously broadcast updated information about the work zone.	TMS-to-vehicle data transfer includes the following: Continuously broadcast updated information about the work zone.	TMS-to-vehicle data transfer includes the following: Continuously broadcast updated information about the work zone.	TMS-to-vehicle data transfer includes the following: Continuously broadcast updated information about the work zone.	TMS-to-vehicle data transfer includes the following: Continuously broadcast updated information about the work zone.	TMS-to-vehicle data transfer includes the following: Continuously broadcast updated information about the work zone.
Manage site	A	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast location data and speeds, providing any changes to the TMS (e.g., vehicles following detour suggestions), as well as weather-related data. 2. Work zone vehicles at the work zone continue to inform TMS of their exact locations and situations, as well as changes in the configuration of the work zone; this allows the TMS to update the geofence and other information being broadcast.	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast location data and speeds, providing any changes to the TMS (e.g., vehicles following detour suggestions), as well as weather-related data. 2. Work zone vehicles at the work zone continue to inform TMS of their exact locations and situations, as well as changes in the configuration of the work zone; this allows the TMS to update the geofence and other information being broadcast.	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast location data and speeds, providing any changes to the TMS (e.g., vehicles following detour suggestions), as well as weather-related data. 2. Work zone vehicles at the work zone continue to inform TMS of their exact locations and situations, as well as changes in the configuration of the work zone; this allows the TMS to update the geofence and other information being broadcast.	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast location data and speeds, providing any changes to the TMS (e.g., vehicles following detour suggestions), as well as weather-related data. 2. Work zone vehicles at the work zone continue to inform TMS of their exact locations and situations, as well as changes in the configuration of the work zone; this allows the TMS to update the geofence and other information being broadcast.	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast location data and speeds, providing any changes to the TMS (e.g., vehicles following detour suggestions), as well as weather-related data. 2. Work zone vehicles at the work zone continue to inform TMS of their exact locations and situations, as well as changes in the configuration of the work zone; this allows the TMS to update the geofence and other information being broadcast.	Vehicle-to-TMS data transfer includes the following: 1. Continuously broadcast location data and speeds, providing any changes to the TMS (e.g., vehicles following detour suggestions), as well as weather-related data. 2. Work zone vehicles at the work zone continue to inform TMS of their exact locations and situations, as well as changes in the configuration of the work zone; this allows the TMS to update the geofence and other information being broadcast.

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Manage site	A	V2V data transfer includes the following: Work zone vehicles operating within and in and out of the work zone continue to inform other vehicles of their exact locations and situations, as well as changes in the configuration of the work zone.	V2V data transfer includes the following: Work zone vehicles operating within and in and out of the work zone continue to inform other vehicles of their exact locations and situations, as well as changes in the configuration of the work zone.	V2V data transfer includes the following: Work zone vehicles operating within and in and out of the work zone continue to inform other vehicles of their exact locations and situations, as well as changes in the configuration of the work zone.	V2V data transfer includes the following: Work zone vehicles operating within and in and out of the work zone continue to inform other vehicles of their exact locations and situations, as well as changes in the configuration of the work zone.	V2V data transfer includes the following: Work zone vehicles operating within and in and out of the work zone continue to inform other vehicles of their exact locations and situations, as well as changes in the configuration of the work zone.	V2V data transfer includes the following: Work zone vehicles operating within and in and out of the work zone continue to inform other vehicles of their exact locations and situations, as well as changes in the configuration of the work zone.
Manage site	B	TMS-to-vehicle data transfer includes the following in addition to Class A: 1. Continuously broadcast updated information about the work zone. 2. Transmit proper staging location to vehicle.	TMS-to-vehicle data transfer includes the following in addition to Class A: 1. Continuously broadcast updated information about the work zone. 2. Transmit proper staging location to vehicle.	TMS-to-vehicle data transfer includes the following in addition to Class A: 1. Continuously broadcast updated information about the work zone. 2. Transmit proper staging location to vehicle.	TMS-to-vehicle data transfer includes the following in addition to Class A: 1. Continuously broadcast updated information about the work zone. 2. Transmit proper staging location to vehicle.	TMS-to-vehicle data transfer includes the following in addition to Class A: 1. Continuously broadcast updated information about the work zone. 2. Transmit proper staging location to vehicle.	TMS-to-vehicle data transfer includes the following in addition to Class A: 1. Continuously broadcast updated information about the work zone. 2. Transmit proper staging location to vehicle.
Manage site	B	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.
Manage site	B	V2V data transfer includes the following: Same as work zone vehicles in the respond operational action.	V2V data transfer includes the following: Same as work zone vehicles in the respond operational action.	V2V data transfer includes the following: Same as work zone vehicles in the respond operational action.	V2V data transfer includes the following: Same as work zone vehicles in the respond operational action.	V2V data transfer includes the following: Same as work zone vehicles in the respond operational action.	V2V data transfer includes the following: Same as work zone vehicles in the respond operational action.
Manage site	C	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.
Manage site	C	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.
Manage site	C	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.
Manage traffic	No cooperative automation	Operate as TMSs currently d, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do without automation and/or communications between TMSs and vehicles.
Manage traffic	A	TMS internal data transfer includes the following: 1. Activate detours. 2. Set up traffic control devices at work zone. 3. Monitor travel conditions around work zone (e.g., status of devices, location of work trucks, and determination of queues) and on freeways and arterials (e.g., travel times and level of service).	TMS internal data transfer includes the following in addition to Level 0: Provide additional details regarding work zone, including location of cones for merging, layout of end of incident site, and how to navigate it (important because lane delineations might no longer be valid).	TMS internal data transfer includes the following in addition to Level 0: Provide additional details regarding work zone, including location of cones for merging, layout of end of incident site, and how to navigate it (important because lane delineations might no longer be valid).	TMS internal data transfer includes the following in addition to Level 0: Provide additional details regarding work zone, including location of cones for merging, layout of end of incident site, and how to navigate it (important because lane delineations might no longer be valid).	TMS internal data transfer includes the following in addition to Level 0: Provide additional details regarding work zone, including location of cones for merging, layout of end of incident site, and how to navigate it (important because lane delineations might no longer be valid).	TMS internal data transfer includes the following in addition to Level 0: Provide additional details regarding work zone, including location of cones for merging, layout of end of incident site, and how to navigate it (important because lane delineations might no longer be valid).

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Manage traffic	A	TMS-to-vehicle data transfer includes the following: 1. Create and broadcast geographic layout of incident site (MAP). 2. Continuously broadcast updates of work zone activities affecting approaching vehicles (e.g., location of work zone vehicles, employees, estimated work zone duration, and weather changes).	TMS-to-vehicle data transfer includes the following: 1. Create and broadcast geographic layout of incident site (MAP). 2. Continuously broadcast updates of work zone activities affecting approaching vehicles (e.g., location of work zone vehicles, employees, estimated work zone duration, and weather changes).	TMS-to-vehicle data transfer includes the following: 1. Create and broadcast geographic layout of incident site (MAP). 2. Continuously broadcast updates of work zone activities affecting approaching vehicles (e.g., location of work zone vehicles, employees, estimated work zone duration, and weather changes).	TMS-to-vehicle data transfer includes the following: 1. Create and broadcast geographic layout of incident site (MAP). 2. Continuously broadcast updates of work zone activities affecting approaching vehicles (e.g., location of work zone vehicles, employees, estimated work zone duration, and weather changes).	TMS-to-vehicle data transfer includes the following: 1. Create and broadcast geographic layout of incident site (MAP). 2. Continuously broadcast updates of work zone activities affecting approaching vehicles (e.g., location of work zone vehicles, employees, estimated work zone duration, and weather changes).	TMS-to-vehicle data transfer includes the following: 1. Create and broadcast geographic layout of incident site (MAP). 2. Continuously broadcast updates of work zone activities affecting approaching vehicles (e.g., location of work zone vehicles, employees, estimated work zone duration, and weather changes).
Manage traffic	A	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds, providing any changes to the TMS.	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds, providing any changes to the TMS.	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds, providing any changes to the TMS.	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds, providing any changes to the TMS.	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds, providing any changes to the TMS.	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds, providing any changes to the TMS.
Manage traffic	A	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.
Manage traffic	B	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: In addition to Class A: 1. Create and broadcast updates of geographic layout of work zone site (MAP). 2. Provide more details regarding work zone layout, including location of cones for merging, layout of end of work zone site, and how to navigate it (important because lane delineations might no longer be valid).	TMS-to-vehicle data transfer includes the following: In addition to Level 1, same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: In addition to Level 1, same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: In addition to Level 1, same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: In addition to Level 1, same as Class A for this operational action.
Manage traffic	B	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.
Manage traffic	B	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: Maneuvering is performed in accordance with rules established by deployed geofences and travel direction.	V2V data transfer includes the following in addition to Level 1: Vehicles broadcast their intentions and observe those of neighboring vehicles. They develop trajectories to politely maneuver within the traffic stream defined in relation to their neighbors' plans. Maneuvering is performed in accordance with rules established by deployed geofences and travel direction.	V2V data transfer includes the following in addition to Level 1: Vehicles broadcast their intentions and observe those of neighboring vehicles. They develop trajectories to politely maneuver within the traffic stream defined in relation to their neighbors' plans. Maneuvering is performed in accordance with rules established by deployed geofences and travel direction.	V2V data transfer includes the following in addition to Level 1: Vehicles broadcast their intentions and observe those of neighboring vehicles. They develop trajectories to politely maneuver within the traffic stream defined in relation to their neighbors' plans. Maneuvering is performed in accordance with rules established by deployed geofences and travel direction.	V2V data transfer includes the following in addition to Level 1: Vehicles broadcast their intentions and observe those of neighboring vehicles. They develop trajectories to politely maneuver within the traffic stream defined in relation to their neighbors' plans. Maneuvering is performed in accordance with rules established by deployed geofences and travel direction.

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Manage traffic	C	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.
Manage traffic	C	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.
Manage traffic	C	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.
Terminate event	No cooperative automation	Operate as TMSs do without automation and/or communications between TMSs and vehicles.	Operate as TMSs do without automation and/or communications between TMSs and vehicles.	Operate as TMSs do without automation and/or communications between TMSs and vehicles.	Operate as TMSs do without automation and/or communications between TMSs and vehicles.	Operate as TMSs do without automation and/or communications between TMSs and vehicles.	Operate as TMSs do without automation and/or communications between TMSs and vehicles.
Terminate event	A	TMS internal data transfer includes the following: Collect/remove debris, and so on, from affected roadway lanes	TMS internal data transfer includes the following: Collect/remove debris, and so on, from affected roadway lanes	TMS internal data transfer includes the following: Collect/remove debris, and so on, from affected roadway lanes	TMS internal data transfer includes the following: Collect/remove debris, and so on, from affected roadway lanes	TMS internal data transfer includes the following: Collect/remove debris, and so on, from affected roadway lanes	TMS internal data transfer includes the following: Collect/remove debris, and so on, from affected roadway lanes
Terminate event	A	TMS-to-vehicle data transfer includes the following: 1. Collect/remove debris, and so on, from affected roadway lanes. 2. Create and broadcast geographic layout of changing incident site (MAP). 3. Continuously broadcast updates of work zone activities affecting approaching vehicles (e.g., new location of first responder vehicles, employees, estimated work zone duration, and weather changes).	TMS-to-vehicle data transfer includes the following: 1. Collect/remove debris, and so on, from affected roadway lanes. 2. Create and broadcast geographic layout of changing incident site (MAP). 3. Continuously broadcast updates of work zone activities affecting approaching vehicles (e.g., new location of first responder vehicles, employees, estimated work zone duration, and weather changes).	TMS-to-vehicle data transfer includes the following: 1. Collect/remove debris, and so on, from affected roadway lanes. 2. Create and broadcast geographic layout of changing incident site (MAP). 3. Continuously broadcast updates of work zone activities affecting approaching vehicles (e.g., new location of first responder vehicles, employees, estimated work zone duration, and weather changes.	TMS-to-vehicle data transfer includes the following in addition to Level 0 through Level 2: Transmit notification to vehicle to inform driver that vehicle is ready to take over control after work zone is cleared. (Not clear whether this is a vehicle-internal decision based on location).	TMS-to-vehicle data transfer includes the following in addition to Level 0 through Level 2: Create and broadcast updates of geographic layout of the work zone (MAP). (Note that at these Automation Levels, the TMC does not need to send a notification to driver to assume control of the vehicle).	TMS-to-vehicle data transfer includes the following n addition to Level 0 through Level 2: Create and broadcast updates of geographic layout of the work zone (MAP). (Note that at these Automation Levels, the TMC does not need to send a notification to driver to assume control of the vehicle).
Terminate event	A	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds, providing any changes to the TMS.	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds, providing any changes to the TMS.	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds, providing any changes to the TMS.	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds, providing any changes to the TMS.	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds, providing any changes to the TMS.	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds, providing any changes to the TMS.
Terminate event	A	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.
Terminate event	B	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.
Terminate event	B	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Terminate event	B	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: Maneuvering is performed in accordance with rules established by deployed geofences and travel direction.	V2V data transfer includes the following in addition to Level 1: Vehicles broadcast their intentions and observe those of neighboring vehicles, including departing work zone vehicles. They develop trajectories to politely maneuver within the traffic stream that they understand from their neighbors' plans. Maneuvering is performed in accordance with rules established by deployed geofences and travel direction.	V2V data transfer includes the following in addition to Level 1: Vehicles broadcast their intentions and observe those of neighboring vehicles, including departing work zone vehicles. They develop trajectories to politely maneuver within the traffic stream that they understand from their neighbors' plans. Maneuvering is performed in accordance with rules established by deployed geofences and travel direction.	V2V data transfer includes the following in addition to Level 1: Vehicles broadcast their intentions and observe those of neighboring vehicles, including departing work zone vehicles. They develop trajectories to politely maneuver within the traffic stream that they understand from their neighbors' plans. Maneuvering is performed in accordance with rules established by deployed geofences and travel direction.	V2V data transfer includes the following in addition to Level 1: Vehicles broadcast their intentions and observe those of neighboring vehicles, including departing work zone vehicles. They develop trajectories to politely maneuver within the traffic stream that they understand from their neighbors' plans. Maneuvering is performed in accordance with rules established by deployed geofences and travel direction.
Terminate event	C	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.
Terminate event	C	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.
Terminate event	C	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.
Recover	No cooperative automation	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.	Operate as TMSs currently do, without automation and/or communications between TMSs and vehicles.
Recover	A	TMS internal data transfer includes the following: 1. Broadcast updated work zone information, including final debris removal and final opening of all lanes and shoulders. 2. Return to normal operations. 3. Capture and store all information received from vehicles.	TMS internal data transfer includes the following: 1. Broadcast updated work zone information, including final debris removal and final opening of all lanes and shoulders. 2. Return to normal operations. 3. Capture and store all information received from vehicles.	TMS internal data transfer includes the following: 1. Broadcast updated work zone information, including final debris removal and final opening of all lanes and shoulders. 2. Return to normal operations. 3. Capture and store all information received from vehicles.	TMS internal data transfer includes the following: 1. Broadcast updated work zone information, including final debris removal and final opening of all lanes and shoulders. 2. Return to normal operations. 3. Capture and store all information received from vehicles.	TMS internal data transfer includes the following: 1. Broadcast updated work zone information, including final debris removal and final opening of all lanes and shoulders. 2. Return to normal operations. 3. Capture and store all information received from vehicles.	TMS internal data transfer includes the following: 1. Broadcast updated work zone information, including final debris removal and final opening of all lanes and shoulders. 2. Return to normal operations. 3. Capture and store all information received from vehicles.
Recover	A	TMS-to-vehicle data transfer includes the following: 1. Create and broadcast geographic layout of changing incident site (MAP). 2. Continuously broadcast updates of work zone activities affecting approaching vehicles (e.g., new location of work zone vehicles, employees, estimated work zone duration, and weather changes).	TMS-to-vehicle data transfer includes the following: 1. Create and broadcast geographic layout of changing incident site (MAP). 2. Continuously broadcast updates of work zone activities affecting approaching vehicles (e.g., new location of work zone vehicles, employees, estimated work zone duration, and weather changes)	TMS-to-vehicle data transfer includes the following: 1. Create and broadcast geographic layout of changing incident site (MAP). 2. Continuously broadcast updates of work zone activities affecting approaching vehicles (e.g., new location of work zone vehicles, employees, estimated work zone duration, and weather changes).	TMS-to-vehicle data transfer includes the following in addition to Level 0 through Level 2: Transmit notification to vehicle to inform driver that vehicle is ready to resume control after the work zone location is cleared. (Not clear whether this is a vehicle-internal decision based on location.)	TMS-to-vehicle data transfer includes the following in addition to Level 0 through Level 2: Create and broadcast updates of geographic layout of former work zone site (i.e., the normal layout of the roadway (MAP)).	TMS-to-vehicle data transfer includes the following in addition to Level 0 through Level 2: Create and broadcast updates of geographic layout of former work zone site (i.e., the normal layout of the roadway (MAP)).

TMS Operational Action	Cooperation Class	Automation Level 0	Automation Level 1	Automation Level 2	Automation Level 3	Automation Level 4	Automation Level 5
Recover	A	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds, providing any changes to the TMS.	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds, providing any changes to the TMS.	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds, providing any changes to the TMS.	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds, providing any changes to the TMS.	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds, providing any changes to the TMS.	Vehicle-to-TMS data transfer includes the following: Continuously broadcast location data and speeds, providing any changes to the TMS.
Recover	A	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: No additional activity under this operational action.
Recover	B	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class A for this operational action.
Recover	B	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class A for this operational action.
Recover	B	V2V data transfer includes the following: No additional activity under this operational action.	V2V data transfer includes the following: Maneuvering is performed in accordance with rules established by deployed geofences and travel direction.	V2V data transfer includes the following in addition to Level 1: Vehicles broadcast their intentions and observe those of neighboring vehicles, including departing responders. They develop trajectories to politely maneuver within the traffic stream that they understand from their neighbors' plans. Maneuvering is performed in accordance with rules established by deployed geofences and travel direction.	V2V data transfer includes the following in addition to Level 1: Vehicles broadcast their intentions and observe those of neighboring vehicles, including departing responders. They develop trajectories to politely maneuver within the traffic stream that they understand from their neighbors' plans. Maneuvering is performed in accordance with rules established by deployed geofences and travel direction.	V2V data transfer includes the following in addition to Level 1: Vehicles broadcast their intentions and observe those of neighboring vehicles, including departing responders. They develop trajectories to politely maneuver within the traffic stream that they understand from their neighbors' plans. Maneuvering is performed in accordance with rules established by deployed geofences and travel direction.	V2V data transfer includes the following in addition to Level 1: Vehicles broadcast their intentions and observe those of neighboring vehicles, including departing responders. They develop trajectories to politely maneuver within the traffic stream that they understand from their neighbors' plans. Maneuvering is performed in accordance with rules established by deployed geofences and travel direction.
Recover	C	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.	TMS-to-vehicle data transfer includes the following: Same as Class B for this operational action.
Recover	C	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.	Vehicle-to-TMS data transfer includes the following: Same as Class B for this operational action.
Recover	C	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following: Same as Class B for this operational action.	V2V data transfer includes the following in addition to the Class B: Vehicles negotiate with each other, cooperatively reentering the newly opened lanes, changing lanes elsewhere, recovering speeds, reforming platoons, and so on, as necessary to pass the former work zone.	V2V data transfer includes the following in addition to the Class B: Vehicles negotiate with each other, cooperatively reentering the newly opened lanes, changing lanes elsewhere, recovering speeds, reforming platoons, and so on, as necessary to pass the former work zone.	V2V data transfer includes the following in addition to the Class B: Vehicles negotiate with each other, cooperatively reentering the newly opened lanes, changing lanes elsewhere, recovering speeds, reforming platoons, and so on, as necessary to pass the former work zone.	V2V data transfer includes the following in addition to the Class B: Vehicles negotiate with each other, cooperatively reentering the newly opened lanes, changing lanes elsewhere, recovering speeds, reforming platoons, and so on, as necessary to pass the former work zone.

AI = artificial intelligence; MAP = map data; SOP = standard operating procedure.

CHAPTER 5. SCENARIOS

This chapter describes representative scenarios for the use cases detailed in chapter 4. The scenarios identify how TMS and CDA stakeholders interact during various events and roadway conditions. These scenarios provide a basic understanding of response actions and specific protocols; they are not intended to be all-inclusive.

The following scenarios are addressed in this chapter:

- Basic travel, including interstate, arterial with traffic signals, ramp metering, and platooning.
- TIM.
- RWM, including winter weather response and black ice on roads.
- WZM.

The scenarios encompass a description of the event, a list of stakeholders, underlying assumptions, and a table relating the TMS operational actions to vehicle Cooperation Classes (i.e., Class A, sharing of status data; Class B, sharing of status data and plans/intentions between TMS and CDA-equipped vehicles and/or among vehicles; Class C, negotiation and mutual planning data between TMSs and CDA-equipped vehicles and/or among CDA-equipped vehicles; and no cooperative automation). For the tables relating the TMS operational actions to vehicle Cooperation Classes, it is assumed that Class A through Class C all support two-way communications. Some other assumptions are repeated for each scenario with applicable modifications.

A TMS uses several sources of data, such as field sensors, third-party providers, and crowdsourcing and has existing standard operating procedures (SOPs) to respond to events. The scenarios in this chapter assume that the typical planned response actions shown in the "No Cooperative Automation" column in each table are performed. However, the scenarios are focused on data provisions by the TMS, CDA-equipped vehicles, and between CDA-equipped vehicles and the enhanced actions made possible by these interactions.

SCENARIO 1: BASIC TRAVEL USE CASE

This scenario consists of subscenarios that describe the operational actions for different circumstances. These subscenarios include the following:

- Passenger vehicles and trucks driving along an arterial where traffic signals are present.
- Passenger vehicles driving along an arterial and merging onto a highway where the onramp is equipped with a ramp-metering system.
- Trucks driving in a platoon along a limited-access highway.

Table 42 summarizes the operational actions supporting the subscenarios. The operational actions that a TMC or TMS must fulfill were identified in the Framework for Basic Travel Use Case section. Table 42 relates these operational actions to the Cooperation Classes of the vehicles on the freeway. The activities a TMS must respond to or initiate due to different SAE

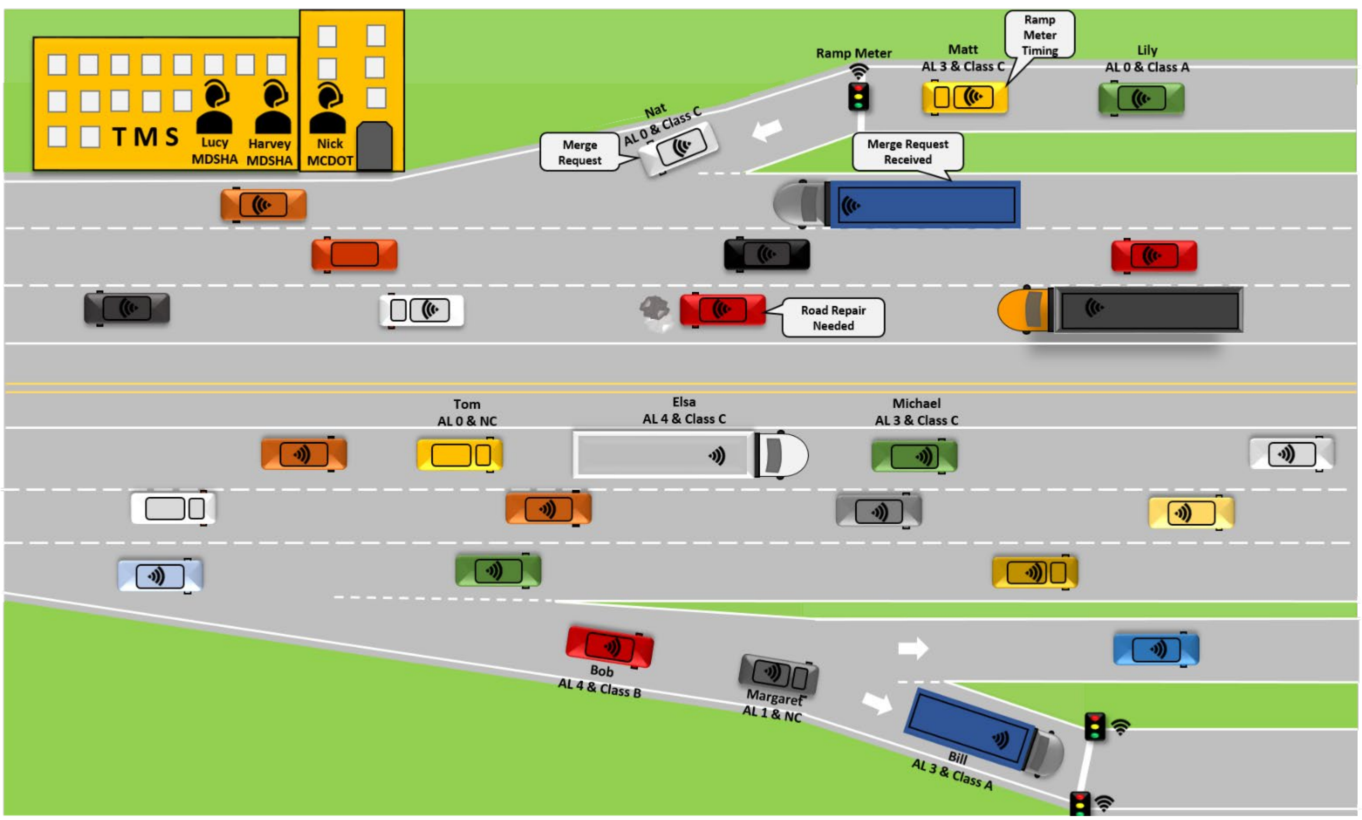
Vehicle Automation Levels are described in table 42. A scenario concept for basic travel is shown in figure 6. The following individuals all play a role in these subscenarios:

- Normal driving along an arterial with traffic signals:
    - Nick is an operator in the Montgomery County, MD, TMC with primary responsibility for managing the traffic signals.
    - Bill drives an Automation Level 3 truck with Cooperation Class A capabilities, meaning it can exchange status messages with other CDA-equipped vehicles. His truck also capable of sending and receiving data to and from a TMC. He travels along Rockville Pike/Route 355 in the southbound direction. His truck is equipped with sensors to identify potholes in the roadway, allowing the vehicle to detect and send information about potholes.
    - Margaret drives an Automation Level 1 vehicle with no cooperative automation capabilities, meaning it is not capable of sending or receiving data from any entity. She is also traveling on Rockville Pike/Route 355 in the southbound direction.
    - Bob drives an Automation Level 4 vehicle with Cooperation Class B capabilities, meaning it can exchange status as well as intention data with other CDA-equipped vehicles. Bob travels eastbound on Wootton Parkway and is about to cross Rockville Pike/Route 355.
- Driving up a ramp with a ramp-metering system and merging onto a highway:
    - Harvey is an operator in the Maryland State Highway TMC in Hanover, MD, with primary responsibility for managing the State's ramp-metering systems. (Maryland does not currently operate ramp meters, but may install them along I–270.)
    - Lily drives a small Automation Level 0 vehicle with Cooperation Class A capabilities, meaning it can exchange status messages with other CDA-equipped vehicles. Status data include information, such as *x*,*y* location; heading; and speed. She travels along Montrose Avenue onto the northbound ramp of I–270 where she encounters the active ramp-metering signal.
    - Matt drives an Automation Level 3 sport utility vehicle (SUV) with Cooperation Class C capabilities, meaning it can send and receive messages with surrounding vehicles, roadside equipment, and back-office software via short- and long-range communications (e.g., dedicated short-range communication [DSRC] and cellular). In addition to sending status data, the vehicle can receive and process ramp-metering and traveler information data from a TMC. He is traveling northbound onto I–270 and is in the vehicle behind Lily.
    - Nat drives an Automation Level 0 sedan with Cooperation Class C capabilities. He is traveling northbound along I–270 at the same time when Lily arrives at the merging point from Montrose Avenue to I–270.
- Driving in a truck platoon along a highway:
    - Lucy is another operator in the Maryland State Highway TMC in Hanover, MD, with primary responsibility for monitoring the State's highways to manage incidents.
    - Michael drives an Automation Level 3 semitractor trailer with Cooperation Class C capabilities, meaning it can cooperate with the TMS and other vehicles by sending and receiving status data as well as intention data. His vehicle also provides and receives data directly to and from his dispatch center (another example of a TMS). He is traveling southbound along I–270.

- Elsa drives an Automation Level 4 truck with Cooperation Class C capabilities. She is in the vehicle behind Michael. Elsa and Michael's trucks can directly cooperate with each other over short-distance V2V communications, and their on-board computers have continuously exchanged data to form a platoon in which their vehicles have engaged for the last 5 mi.
- Tom is driving an Automation Level 0 sports car with no cooperative automation capabilities, meaning it is not capable of sending or receiving data from any entity. He is traveling in the express lane along I–270 and realizes, almost too late, that he needs to merge over to exit to the local lanes.

There are no predefined standard operating procedures (SOPs) for a TMC to execute to manage these subscenarios. The subscenario response actions described in table 42 focus on the enhanced actions made possible by interactions between a TMC with specific functions and CDA-equipped vehicles.

A TMC can obtain detector data from agency-owned detectors, video-detection processing in association with closed-circuit televisions (CCTVs), and third-party data providers who use crowdsourcing. In most cases, a TMC cannot identify individual vehicles, particularly private passenger vehicles; however, some TMCs and third-party data providers can monitor and obtain location and other data from fleet vehicles.



Source: FHWA.
AL = Automation Level; Class = Cooperation Class; NC = no cooperation.

Figure 6. Illustration. Basic travel scenario.

Table 42. Basic travel scenario summary.

Scenario Number	TMS Operational Action	No Cooperative Automation	Cooperation Class A	Cooperation Class B	Cooperation Class C
1	Notify and advise	Subscenario 1: Nick, the Montgomery County, MD, TMC operator responsible for traffic signals, is monitoring the operations of the traffic signals, among his other responsibilities, and determines they work as configured. He has access to CCTVs installed along the critical intersections, but because there is no reported incident or pending event, he turns his attention to other activities.	Subscenario 1: Nick, the Montgomery County, MD, TMC operator, receives the aggregated status message data via the collecting central system software, which automatically evaluates the data received from CDA-equipped vehicles and provides Nick with information about the driving experiences along the arterials, complementing the data he already received from a third-party data provider. The higher resolution data are more accurate, and he can use them to detect unexpected traffic slowdowns and stoppages. Nick upgraded his traffic signal controllers along Rockville Pike/Route 355, which are now continuously broadcasting SPaT information every ¹⁄₁₀ s using short-range communications and the geographic layout of each intersection every 1 s. He does not know if any vehicles are equipped to receive and/or react to this information. However, as he receives the location of CDA-equipped vehicles within his ATMS, the data show that some vehicles are slowing down in front of the traffic signals and do not come to a full stop in front of a red light; there seems to be a pattern to this behavior compared to other intersections without SPaT broadcast capabilities. Based on the information received from vehicles traveling northbound on Rockville Pike/Route 355, such as Bill's, and eastbound on Wootton Parkway, such as Bob's, Nick determines the signal timing plans should be adjusted to reduce the average delay in both directions and schedules this activity for next week. Nick obtains pothole data from Bill's vehicle and creates weekly reports that his central system software automatically forwards to Montgomery County's maintenance department, which will fix them as soon as possible. Bill and Bob drive vehicles that can receive data from traffic signals. Their in-vehicle computers display count-down timers allowing Bill to actively slow down to arrive right on time at the intersection stop, avoiding the need to come to a complete stop, while Bob's Automation Level 4 vehicle automatically processes the data and performs a similar action to Bill's vehicle.	Subscenario 1: Nick, the Montgomery County, MD, TMC operator, is receiving intention data exchanged between CDA-equipped vehicles from his RSUs, which have been configured to capture certain data types exchanged between vehicles to determine potential geometric layout issues leading to near misses. He plans to compare the actual data to the intention data in detail to propose geometric changes along Rockville Pike/Route 355 to increase safety and reduce the likelihood of crashes.	Subscenario 1: As none of the vehicles involved in this subscenario are equipped with Cooperation Class C capabilities, no negotiation or mutual planning between vehicles is performed.

Scenario Number	TMS Operational Action	No Cooperative Automation	Cooperation Class A	Cooperation Class B	Cooperation Class C
1	Notify and advise	Subscenario 2: Harvey, an operator in the Maryland State Highway TMC in Hanover, MD, with primary responsibility for managing the State’s ramp-metering system, just checked and ensured that the ramp meters are running the correct preprogrammed metering plan. He turns his attention to the design of new special event ramp-metering plans.	Subscenario 2: Harvey, an operator in the Maryland State Highway TMC in Hanover, MD, is receiving similar data to Nick’s, but from the highways in their respective areas of responsibilities. Harvey’s ramp-metering units along I–270 were updated last year and are now broadcasting the ramp meter SPaT data every $\frac{1}{10}$ s using short-range communications and the geographic layout of each intersection every 1 s. Based on the information received from vehicles, such as Matt’s, Harvey determines the ramp-metering plans are well-timed and adequate. Lily and Matt drive vehicles that receive data from the ramp meters. Lily, in her Automation Level 0 vehicle, adjusts her speed and arrives at the ramp without stopping. Matt’s Automation Level 3 vehicle performs the same action as Lily’s manual action, but automatically.	Subscenario 2: Harvey, an operator in the Maryland State Highway TMC in Hanover, MD, is receiving any intention data exchanged between CDA-equipped vehicles from his RSUs, which are configured to capture certain data types exchanged between vehicles to determine near misses when merging onto the highway. Like Nick for arterials, Harvey plans to compare the actual data with the intention data in detail to better understand the causal factors contributing to near misses. After Lily’s vehicle enters the merging area, she encounters Nat, who is also in an Automation Level 1 vehicle. Nat’s vehicle, with its Cooperation Class B capabilities, can receive Lily’s current and intended merging speed, location, and heading data. Nat’s on-board computer displays a message to slow down slightly to allow Lily to safely enter the highway.	Subscenario 2: Matt arrives at the onramp right after Lily, who is being let in by Nat’s vehicle, which is slowing down to allow for Lily’s operation. Both Matt and Nat’s vehicles feature Cooperation Class C capabilities, and their vehicles begin cooperating to determine how Matt’s vehicle can merge by constantly exchanging merge-negotiation data. Subsequently, Matt’s vehicle successfully merges onto I–270. In addition to the vehicle-to-vehicle cooperation, the infrastructure understands that it can perform advanced cooperative behavior with Matt’s vehicle and initiates a negotiation to release the vehicle from the ramp meter. Meanwhile, the infrastructure traffic sensors are monitoring mainline I–270 flow upstream of the metered ramp and notice an approaching gap in the right-hand lane. The infrastructure server computes the release timing necessary for Matt’s vehicle to smoothly fill the gap and communicates the plan to Matt’s vehicle. Matt’s vehicle acknowledges that the plan is within its capabilities and serves its mission goals (i.e., it accepts the plan). At the appropriate time, the ramp meter transmits the tailored “Go” signal tagged specifically for Matt’s vehicle, and the vehicle proceeds down the onramp at the agreed acceleration rate, smoothly merging into the gap in mainline traffic so there is no disruption to mainline vehicles.

Scenario Number	TMS Operational Action	No Cooperative Automation	Cooperation Class A	Cooperation Class B	Cooperation Class C
1	Notify and advise	Subscenario 3: Lucy, a colleague of Harvey's in the Maryland State Highway TMC in Hanover, MD, determines there are no current incidents or ongoing work zones that she needs to monitor. She continues to view existing CCTVs along Maryland highways so she is ready to manage future incidents.	Subscenario 3: Lucy, a colleague of Harvey's in the Maryland State Highway TMC in Hanover, MD, is using her central software system, which is continuously receiving speeds, locations, and headings data from suitably equipped vehicles; these include Michael's and Elsa's trucks. Lucy notices on the CCTV that these trucks are operating very close together; she is concerned about the safety and legality of the small gap. She checks the TMC computer system, which is continuously receiving messages from connected vehicles in the vicinity. These messages include vehicle state data and the V2V mobility messages used to negotiate relationships between the trucks. Lucy verifies that these two trucks are operating in an agreed two-vehicle platoon that has speed and gap parameters that comply with Maryland State guidelines for this section of roadway. While Michael and Elsa's vehicles drive in a safe manner, Tom, in his Automation Level 0 vehicle with no cooperative automation, realizes too late that he needs to exit the roadway or miss his exit. He is not aware that the two trucks next to him in the right-hand lane are driving in a coordinated platoon but surmises that the headway is too close for him to squeeze between them. After quickly checking his rearview mirror, Tom brakes and moves behind Elsa's truck, allowing him to barely make his exit. Elsa observes Tom's behavior and is glad to be in a platoon because Tom would have otherwise forced her to make a hard brake with Tom exiting in front of her. Elsa's truck does have onboard vehicle sensors to monitor the location, speed, and heading data of other vehicles surrounding her. The on-board system records Tom's vehicle's behavior and provides this information to Lucy's software as awareness information for later analysis.	Subscenario 3: Lucy, a colleague of Harvey's in the Maryland State Highway TMC in Hanover, MD, is receiving intention data exchanged between CDA-equipped vehicles from her RSUs, which are configured to capture certain data types exchanged between vehicles to determine the number of truck platoons in the area and near misses associated with the truck platoon. Like Harvey for arterials, Lucy plans to compare the actual data with the intention data in detail to better understand the causal factors contributing to near misses.	Subscenario 3: Michael and Elsa's trucks approach the scene already engaged in a two-vehicle platoon with Michael in the lead. They formed the platoon 40 mi back when Elsa entered the highway and their trucks automatically began negotiating operational behavior. Once Elsa's truck automatically maneuvered into place to form the platoon, the two trucks continued active communications to maintain the negotiated relationship. These communications include operating parameters of the platoon (including number and identifiers of vehicles involved); their positions in the platoon; the platoon's target speed, lane, and destination; the target gap; and the maximum allowed number of vehicles. Because Maryland State guidelines allow platoon lengths of three vehicles on this roadway segment, Michael's lead vehicle is continuously broadcasting for another vehicle to join the platoon.

SPaT = signal phase and timing.

SCENARIO 2: TIM USE CASE (MAJOR INCIDENT ON FREEWAY)

This incident occurs in Virginia on a three-lane section of I–66 westbound during morning peak. A passenger vehicle in the middle lane tries to pass a box truck on the right; the vehicle cuts too sharply in front of the box truck, causing a crash.

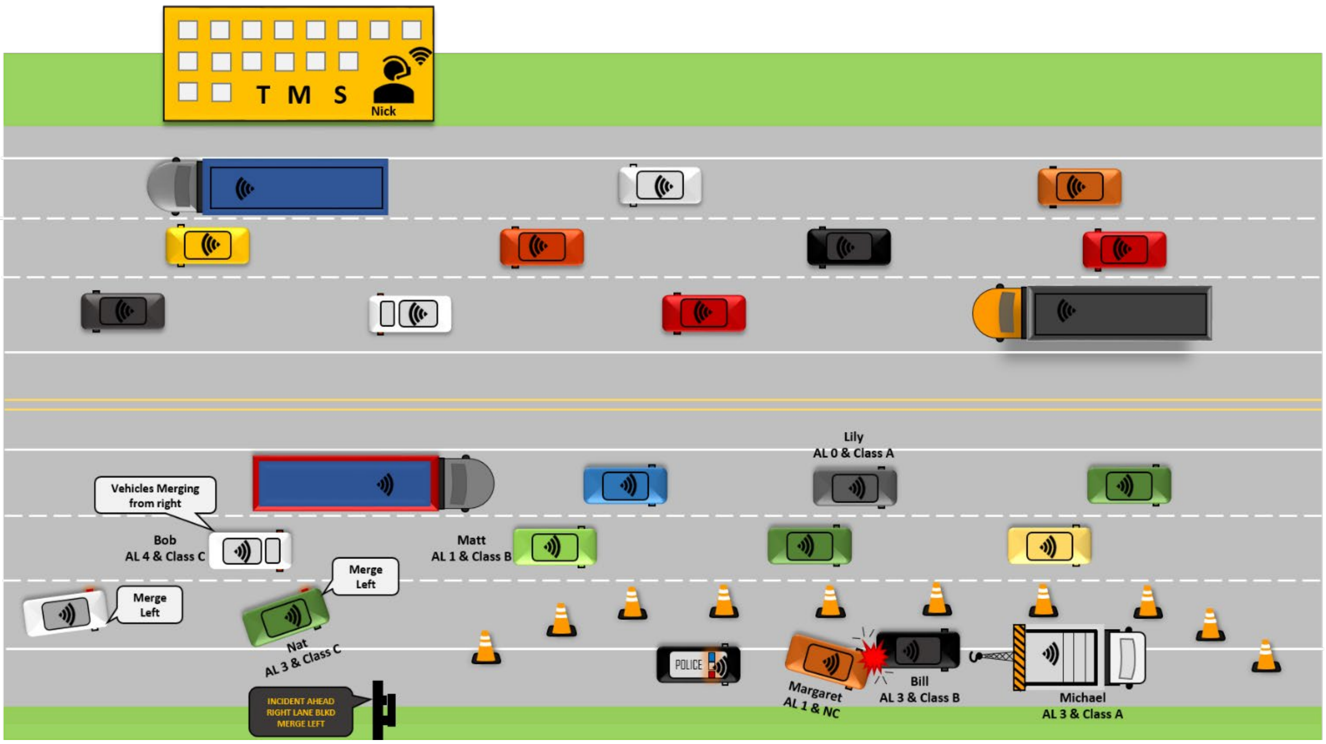
Table 43 summarizes the operation actions performed to address and resolve the incident. Operational actions that a TMC or TMS must fulfill were identified in the Framework for TIM Use Case section. Table 43 relates these operational actions to the Cooperation Classes of the vehicles on the freeway (i.e., no cooperative automation; Class A, sharing of status data; Class B, sharing of status data and plans/intentions between TMS and CDA-equipped vehicles and/or among vehicles; and Class C, negotiation and mutual planning data between TMSs and CDA-equipped vehicles and/or among CDA-equipped vehicles). The activities a TMS must respond to or initiate due to different SAE International Automation Levels are described in table 43. A scenario concept of the TIM is shown in figure 7.

The following individuals play a role in this scenario:

- Nick is an operator in the TMC in Fairfax County, VA, with primary responsibility for managing the incident.
- Bill drives an Automation Level 3 truck with Cooperation Class B capabilities, meaning it can send and receive status and intention data. His truck is one of the vehicles involved in the crash.
- Margaret drives an Automation Level 1 vehicle with no cooperative automation capabilities, meaning it is not capable of sending or receiving data to or from any entity. Her vehicle is one of the vehicles involved in the crash.
- Lily drives a small Automation Level 0 vehicle with Cooperation Class A capabilities, meaning it can send status data, including information, such as x,y location; heading; and speed.
- Matt drives an Automation Level 1 SUV with Cooperation Class B capabilities, meaning it can cooperate with surrounding CDA-equipped vehicles, roadside equipment, and back-office software via various short- or long-range communications technologies (e.g., DSRC and cellular). In addition to sending status data, the vehicle can send vehicle-related and environmental data and receive traveler information data from a TMC. His vehicle also sends and receives mobility messages describing his and other proximate vehicles' future trajectory plans.
- Nat drives an Automation Level 0 sedan with Cooperation Class C capabilities. It can send and receive messages with content similar to Matt's, vehicle but Nat's vehicle can also negotiate with other, similarly equipped, nearby vehicles to coordinate their operations.
- Bob drives an Automation Level 4 SUV with Cooperation Class C capabilities. It has message content and negotiation capabilities similar to Nat's vehicle.
- Michael drives an Automation Level 3 tow truck with Cooperation Class A capabilities, meaning it can send and receive messages. His vehicle provides and receives data directly to and from his dispatch center. Furthermore, his vehicle has on-board sensory

capabilities allowing the measurement of surface temperature, ambient temperature, and precipitation.

During incident response, essential activities are executed following SOPs that are well-defined and assigned to responsible parties. Table 43 considers both the data and interactions sent to and received from TMSs and vehicles, as well as between vehicles themselves (Cooperation Class B and Class C). A TMS may have multiple sources (e.g., traditional and non-TMS-to-vehicle options) for obtaining needed data. Incident data (e.g., detection, verification) can come from agency-owned detectors, CCTVs, and third-party data providers who use crowdsourcing or prediction models based on artificial intelligence (AI), machine-learning algorithms, and so on.



Source: FHWA.
AL = Automation Level; Class = Cooperation Class; NC = no cooperation.

Figure 7. Illustration. TIM scenario.

Table 43. TIM scenario summary.

Number	TMS Operational Action	No Cooperative Automation	Cooperation Class A	Cooperation Class B	Cooperation Class C
1	Detect	Nick, the TMC operator in Fairfax County, VA, receives an incident detection notification from his ATMS, which has a center-to-center interface with the Northern Virginia 911 center. Based on this information, Nick begins verifying this detected incident.	Lily arrives at the incident site in her vehicle with Cooperation Class A capabilities just as the crash occurs. Her vehicle automatically, continuously, and transparently sends basic safety information, such as speed; heading; and *x*,*y* location. Due to the incident, Lily slows down and ultimately comes to a complete stop. Nick, an operator in the TMC in Fairfax County, VA, receives the aggregated basic safety message data via the central system software. The software automatically evaluates the received data from Lily's vehicle and informs Nick that an unexpected traffic slowdown and stoppage occurred. Matt also arrives at the incident site in his vehicle with Cooperation Class B capabilities just as the crash occurs. His vehicle automatically, continuously, and transparently sends basic safety information, such as speed; heading; and *x*,*y* location.	The truck involved in the crash, driven by Bill, is an Automation Level 3 vehicle with Cooperation Class B capabilities. Bill's vehicle automatically detects that it is involved in an incident and broadcasts a crash notification, including placard-like information that the truck carries hazardous materials. Margaret drives the other vehicle involved in the crash. It is an Automation Level 1 vehicle with no cooperative automation capabilities, meaning it is not capable of sending or receiving data from any entity. Because Matt drives an Automation Level 1 vehicle, it detects the incident vehicles as obstacle in the roadway and automatically stops via its automatic emergency braking feature and broadcasts this information to other vehicles and the TMC.	Nat, who is driving an Automation Level 3 vehicle, arrives at the incident site at the same time. His vehicle informs him that an incident occurred ahead; his vehicle automatically slows down and stops and broadcasts this information to other vehicles and the TMC. However, because Nat is in autonomous mode with his vehicle performing the basic driving tasks, his vehicle notifies him to assume control and maneuver past the incident location. Nat's vehicle was broadcasting mobility messages, describing its planned path through the crash vicinity; however, upon detecting the crash and turning control over to Nat, the vehicle broadcasts a new message rescinding its previous plans and informing nearby vehicles that it is now in driving mode. Bob drives an Automation Level 4 vehicle and arrives at the incident site right after Nat. He is engaged in a complex report and does not realize his vehicle has automatically slowed down and changed lanes, negotiating a safe lane change with Nat's vehicle before it went into driver control mode. Even though Bob's vehicle displayed a notice with the reason for the slowdown, the maneuver was based on his vehicle's sensory data plus additional data received from Nat and Matt's vehicles. Ultimately, Bob's vehicle stops and broadcasts this information to other vehicles and the TMC.
2	Verify	Because Nick received the initial incident detection notification from the Northern Virginia 911 center, which received it from a Virginia Highway Patrol officer, the incident is likely real. Nick's ATMS software has the capability to automatically select the nearest pan-tilt-zoom-capable CCTV and turns it toward the suspected incident site. Based on both inputs, he verifies the incident is real, confirming the automated draft incident and turning it into a verified incident.	Nick, the TMC operator, also receives information from the central software system that other vehicles show the same behavior as Lily's vehicle (i.e., changes in speed and *x*,*y* locations indicate a slowdown and/or stoppage), which verifies the existence of the detected incident. Otherwise, Nick relies on nearby CCTVs and detector data, as well as data from third-party data providers, including police and 911 centers, to verify the existence of the incident.	Bill's truck, with Automation Level 3 and Cooperation Class B capabilities, broadcasts that it is involved in the crash—effectively verifying the incident. Nat and Bob's vehicles are close enough to see the crash and broadcast incident detection messages. These messages are received by the TMC as further verification but are also available for approaching vehicles to provide advanced warning before the TMC can even broadcast the verified incident information.	—

Number	TMS Operational Action	No Cooperative Automation	Cooperation Class A	Cooperation Class B	Cooperation Class C
3	Notify and advise	Following established SOPs developed for use within the agency and by partner agencies, Nick, the TMC operator, informs the affected agencies of the incident, its location, expected duration, lane closures, and recommended detours for each direction. He can see the incident via a nearby CCTV, which is helpful because his TMC recently established a video-sharing system. Nick uses his mapping tools to note the exact location of the incident and draws a border around the site that allows room for response personnel and equipment to work safely. The TMC system then expands that border upstream of the incident to provide sufficient space for approaching vehicles to adjust to the new travel restrictions before reaching the site. Nick informs local radio and television stations to include an incident notification in their traffic reports. His agency recently retired their highway advisory radio system so he can no longer use this resource.	Nick, the TMC operator, receives and confirms the mobility message broadcast to vehicles of all Automation Levels near the incident. The message contains details on the incident, geofence boundaries and travel direction, dynamic speed harmonization, lane control when possible, applicable detour information, and queue-warning information. Lily's Cooperation Class A vehicle receives the mobility message from the TMC describing the incident and displays it for Lily to see. As she was first on the scene, this information is not new to her, but she feels comforted that it was quickly processed and accurately describes the situation.	Matt's Cooperation Class B vehicle receives the mobility message announcing the incident, which correlates with his vehicle's understanding of the situation. Because his is only an Automation Level 1 vehicle, and traffic is now heavy, Matt is restricted to assuming control of his vehicle and manually driving away from the situation.	Nick, the TMC operator, uses predictive analytics in the TMC that tell him balancing the roadway loads around the incident makes sense. He sends out requests to vehicles upstream of the incident (i.e., geofenced) to take an alternative route. The request is understood to imply that an acknowledgment is expected. Nat and Bob's vehicles, with their Cooperation Class C capabilities, both acknowledge the request to take a different route; they indicate they will take the alternate route, then execute the route change. Bob, still engaged in his report, does not notice the redirection because his Automation Level 4 vehicle performs the maneuvers automatically.
4	Respond	Considering the increasing backups and the danger of secondary rear-end crashes, Nick determines that he needs to warn motorists approaching the crash site as quickly as possible. Looking at the map-centric ATMS software package at his fingertips, Nick selects the nearest VMSs and places appropriate messages on them, warning approaching motorists upstream of the incident site. In the direction of the incident, he informs drivers what happened, where downstream it happened, and the lanes impacted. In the opposite direction, the message warns drivers of an upcoming slow down due to rubbernecking. He also places a message upstream on VMSs, suggesting drivers may want to detour around the incident.	During this stage, all vehicles (i.e., passenger, trucks, and first responders), regardless of Automation Level, continuously broadcast their location data and speeds to the TMC. Nick, the TMC operator, uses these data to update the notification messages and operational responses as needed. Nick also receives information from other responders for additional updates.	Nick, the TMC operator, confirms a system-generated response plan, including broadcasting safe speeds when approaching the incident site. The TMC broadcasts route-guidance details specific to first responder vehicles and tow trucks arriving at the incident site, including staging locations, and so on. During this time, the TMC continuously sends updates about available detours. The TMC broadcasts information for vehicles with Cooperation Class B capabilities. Having previously made plans with regional agencies about which network routes to use when responding to incidents at various locations, Nick determines the best emergency route for this incident and provides the information to first responders. Vehicles with Automation Level 4 capabilities can receive and react to TMC-defined detours within geofenced areas, allowing for limited network load-balancing. Vehicles with Automation Level 5 capabilities receive this information for the entire network. Michael is dispatched to the incident site to provide towing services in his tow truck with Automation Level 3 capabilities. His vehicle has on-board sensory capabilities that measure surface temperature, ambient temperature, and precipitation. Michael's vehicle is continuously providing updated weather information to the TMC while also sending data to his dispatch center, informing the garage technicians that the air pressure in his tires are low. The truck also broadcasts its planned trajectory as it approaches the incident site.	Nat and Bob, while intending to take the recommended detour, are stuck in traffic and only slowly approaching the detour point. Their Class C cooperative vehicles detect messages coming from Michael's tow truck, indicating its intended path of travel to the site. Both vehicles automatically pull onto the shoulder to free up space in the travel lane so that the tow truck can approach more quickly and speed the incident resolution.

Number	TMS Operational Action	No Cooperative Automation	Cooperation Class A	Cooperation Class B	Cooperation Class C
5	Manage site	Nick, the TMC operator, continues to monitor the crash site via CCTV, receives updates from the Northern Virginia 911 center dispatch, and notifies his partner agencies. Onsite, the responsible police officer and other responders perform their duties.	During this time, all vehicles (i.e., passenger, trucks, and first responders), regardless of Automation Level, continuously broadcast their location data and speeds to the TMC. The continuous updates reveal that 7 percent of vehicles followed the detour recommendations (Cooperation Class A vehicles read message on roadside signs because they cannot receive data). Nick, the TMC operator, uses the data to accurately assess incident conditions.	Nick, the TMC operator, confirms system-generated broadcasts of the incident site, including detailed first responder vehicle locations and changes to the site layout. When Michael, driving a tow truck with Automation Level 3 capabilities, arrives at the incident site, he receives detailed information about his staging location within the incident site from the TMC. Other first responder vehicles receive similar information for their staging locations. Michael's vehicle continues to broadcast location/speed data and updated weather information from its on-board sensory equipment to the TMC. Other CDA-equipped first responder vehicles broadcast their arrival and activity data.	—
6	Manage traffic	Nick, the TMC operator, continues to monitor the crash site via CCTV. He receives updates from the Northern Virginia 911 center dispatch and, informs other affected agencies. He also receives updates from call-ins from tow truck operators. Onsite, the responsible police officer and other first responders perform their duties as they would without advanced vehicles.	All vehicles (i.e., passenger, trucks, and first responders), regardless of Automation Level, continuously broadcast their location data and speeds to the TMC.	Nick, the TMC operator, continues to receive and confirm system-generated broadcasts of the incident site, including detours, detailed first responder vehicle locations, incident activities affecting approaching vehicles, estimated end-of-incident duration, weather changes, determination of queues, travel conditions around incident, and changes to the site layout. The TMC central software system provides the following additional information: • For Automation Level 1 and Automation Level 2 vehicles, create and broadcast updates of geometric layout of incident site (MAP); provide additional details regarding incident layout, including locations of cones for merging, layout of incident site end, and how to navigate it, which is important because lane delineations may no longer be valid. • For Automation Level 4 and Automation Level 5 vehicles, create and broadcast geometric layout of the incident site (MAP), including locations of cones, incident-response vehicles, and first responders (when known), and so on.	—

Number	TMS Operational Action	No Cooperative Automation	Cooperation Class A	Cooperation Class B	Cooperation Class C
7	Clear and terminate event	Nick, the TMC operator, continues to monitor the crash site via CCTV, receive updates from the Northern Virginia 911 center dispatch, and inform the other affected agencies. He also receives updates from tow truck operators who notify him the crash truck and vehicles are being removed, along with roadway debris. Onsite, the responsible police officer and other first responders perform their duties as they would without advanced vehicles.	All vehicles (i.e., passenger, trucks, and first responders), regardless of Automation Levels, continuously broadcast their location data and speeds to the TMC.	Nick, the TMC operator, continues to receive and confirm system-generated broadcasts of the incident site, including status of wreckage removal, debris, and so on, from affected roadway lanes; detours; detailed first responder vehicle locations; incident activities affecting approaching vehicles; estimated end-of-incident duration; weather changes; determination of queues; travel conditions around incident; and changes to the site layout. The TMC central software system also updates and broadcasts the geometric layout of the incident site (MAP), including locations of cones, incident-response vehicles, first responders (when known), and so on, for Automation Level 4 and Automation Level 5 vehicles:	—
8	Recover	Nick, the TMC operator, receives a final update from the Northern Virginia 911 center dispatch stating that all first responder vehicles left the crash scene, which he confirms via CCTV. Following the SOPs, he notifies the affected agencies of the incident recovery, removes the incident messages from the VMS, and prepares an incident report for later analysis and evaluation.	All vehicles (i.e., passenger, trucks, and first responders), regardless of Automation Levels, continuously broadcast their location data and speeds to the TMC. After determining the incident is terminated and all lanes reopened, Nick receives and confirms a system-generated mobility message announcing that all lanes are accessible and the geofence information has expired.	Vehicles able to receive and process the mobility messages from the TMC see the geofence has expired and understand the speed limits and lane geometry returned to normal, which confirms their sensor observations. Without this confirmation, CDA-equipped vehicles may have been uncertain as to whether the geofence was complete or their communication mechanisms were faulty.	—

—No data.
ATMS = active traffic management system; MAP = map data; VMS = variable message sign.

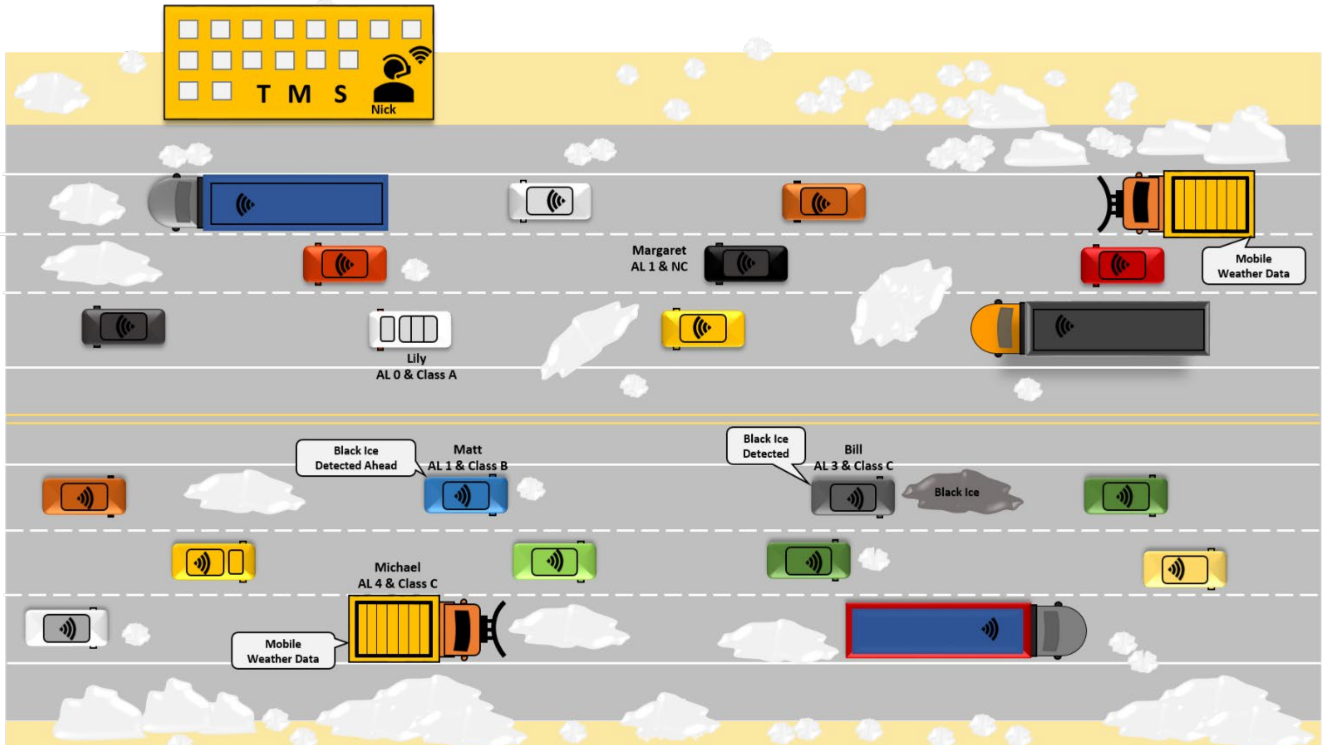
SCENARIO 3: RWM USE CASE

This scenario describes an RWM incident on I–70 in Denver, CO. The scenario addresses operational actions related to snow clearance and black ice on the road as shown in table 44. The scenario also relates actions described in table 44 to the Cooperation Classes of vehicles on the freeway. The activities the TMC must respond to or initiate due to different SAE International Automation Levels are described in table 44. A scenario concept of the RWM is shown in figure 8.

The following individuals all play a role in this scenario:

- Nick is an operator in the Denver County, CO, TMC with primary responsibility for managing the incident.
- Michael drives an Automation Level 4 snowplow with Cooperation Class C capabilities, meaning it is able to send and receive messages; measure pavement temperature, ambient temperature, precipitation, and so on; and cooperate and negotiate with other CDA-equipped vehicles to perform coordinated actions.
- Bill drives an Automation Level 3 truck with Cooperation Class C capabilities. It can send and receive data similar to Michael's snowplow, but Bill's truck can send and receive status and intention data and can negotiate with other CDA-equipped vehicles to coordinate actions.
- Margaret drives an Automation Level 1 vehicle with no cooperative automation capabilities, meaning it is not able to send or receive data from any entity.
- Lily drives a small Automation Level 0 vehicle with Cooperation Class A capabilities, meaning it can send and receive status data.
- Matt drives an Automation Level 1 SUV with Cooperation Class C capabilities, meaning it can send and receive status and intention data to and from surrounding vehicles, roadside equipment, and back-office software via short- and long-range communication systems (e.g., DSRC and cellular). In addition to sending basic safety data, the vehicle can send vehicle-related and environmental data and receive traveler information data from a TMC.

Depending on the weather emergency, TMCs use road weather information systems (RWISs), the National Weather Service, third-party weather data providers, and so on, to gather information on existing and forecasted weather conditions. These data support decisionmaking for responding to weather events, such as winter storms, flooding, and hurricanes. For example, the data can be used to make decisions on materials and equipment needed, staffing levels, and timing of snow plowing activities in response to winter storms. The scenario response actions described in table 44 assume that all typical response actions are performed; it focuses on the enhanced actions made possible by CDA-equipped vehicle interactions.



Source: FHWA.
AL = Automation Level; Class = Cooperation Class; NC = no cooperation.

Figure 8. Illustration. RWM scenario.

Table 44. RWM scenario summary.

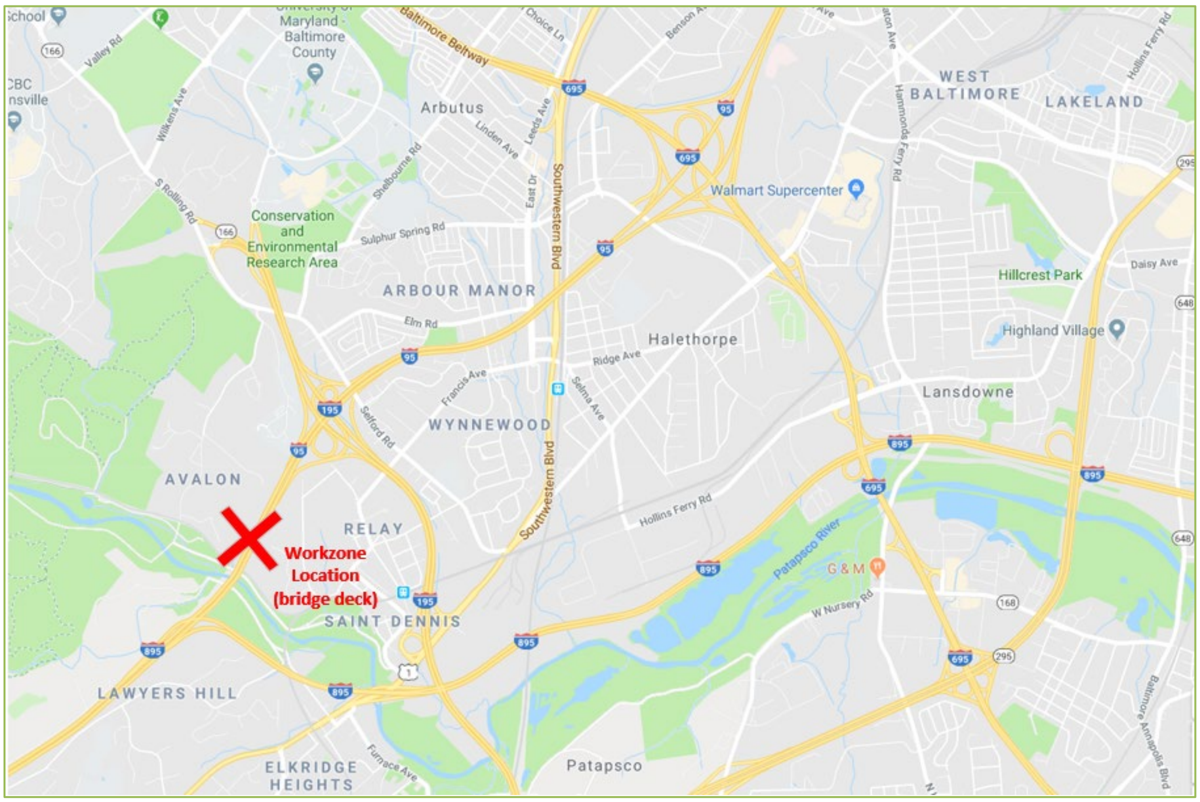
Number	TMS Operational Action	No Cooperative Automation	Cooperation Class A	Cooperation Class B	Cooperation Class C
1	Detect	Nick, the TMC operator in the Denver, CO, area, has been monitoring a snowstorm for the past several hours. The forecast calls for 6 to 8 inches of snow for the Denver area. The first flurries have already begun. Nick accesses weather data from RWIS stations in the Denver region and from third-party weather data providers for a more detailed view of current and forecasted conditions.	Lily's vehicle with Cooperation Class A capabilities is automatically, continuously, and anonymously providing location information to the TMC. Nick's weather modeling system at the TMC receives aggregated data from vehicles via the V2X software module and models the weather patterns for the next 12 h. The outputs provide him a high-resolution view of potential snow accumulations along the roadway. Machine-learning algorithms use historical data from previous storms to identify sections of the roadway network where travel will be particularly hazardous during the snowstorm. Michael, along with other vehicles in the fleet, completed pretreatment operations a few hours ago and is on standby in his Automation Level 4 vehicle with Cooperation Class B capabilities. He is awaiting information from Nick and maintenance dispatch to begin the snow-clearing work. Bill's Automation Level 3 vehicle with Cooperation Class B capabilities is automatically, continuously, and anonymously sending weather data to the TMC. As the snowfall becomes heavier, the vehicle's wipers move faster and send this information to the TMC. Matt's Automation Level 1 vehicle with Cooperation Class B capabilities and Bill's vehicle both infer the presence of black ice along a horizontal curve on I–70 that could be hazardous to vehicles.	—	—
2	Notify and advise	Nick posts snow and icy conditions alerts on DMSs. A hazard alert is posted on a DMS located a few miles upstream of the black ice location.	Nick receives and confirms the weather information to be broadcasted to vehicles of all Automation Levels, including a hazard alert to vehicles a few miles upstream of the black ice location. All vehicles, regardless of Automation Level, broadcast their vehicle locations, speed, and heading, as well as vehicle environmental data, braking status, and vehicle size. Michael, Bill, Margaret, Lily, and Matt's vehicles all broadcast these data, which can be received by the TMC and vehicles in the geofenced area around the weather zone.	Nick's system enables him to determine detailed weather forecasts for the weather-related geofenced area and broadcasts that data. All vehicles with Cooperation Class A and higher capabilities broadcast and receive data from other vehicles' path predictions, including detour or stopping advisories, which are relevant to Margaret, Lily and Matt's vehicles. Michael is driving a snow-removal vehicle during the weather event.	—

Number	TMS Operational Action	No Cooperative Automation	Cooperation Class A	Cooperation Class B	Cooperation Class C
3	Control	As the snow gets heavier, Nick's ATMS software recommends reducing the speed limits along the different sections of the roadway, and the new limits are posted on DMSs. Margaret is driving on I–70 in her Automation Level 1 vehicle with no cooperative automation capabilities. She is listening to weather updates on her car radio, hoping to be at her destination before the snow gets too heavy. She sees a DMS with the recommended reduced speed limit. Lily also sees the posted speed limit on the DMS and reduces her speed.	Nick receives and confirms the message to be broadcasted to vehicles of all Automation Levels and classes, including reduced speed limits within specific geofences identified based on the continuous weather information from vehicles, RWISs, and third-party data. The message contains details on the location, speed limit, and lane control, as well as black ice, road closures, snow clearance status along its route, and location of snowplows on the roadway within geofenced areas. The central software system also provides additional information for Automation Level 1 through Automation Level 3. Such vehicles instruct drivers to assume control and reduce speed and identifies the location of black ice. Vehicles of all Automation Levels within the Cooperation Class A group broadcast location, speed, and heading data, as well as onboard equipment failures and vehicle environmental data; this includes Michael, Bill, Margaret, Lily, and Matt's vehicles. These data can be received by the TMC and by vehicles in the geofenced area around the weather zone.	All vehicles with Cooperation Class A and higher capabilities broadcast and receive from other vehicles their path predictions, including intended trajectories. This is relevant to Michael, Bill, Lily, and Matt's vehicles. Margaret's vehicle has no cooperative automation capabilities and cannot cooperate with other vehicles.	Michael's vehicle negotiates with Bill's vehicle to determine road weather condition clearance areas. The other vehicles in this scenario do not support Cooperation Class C capabilities.
4	Treat and maintain	The ATMS recommends treatment plans to Nick based on weather data and information from the maintenance fleet.	Nick communicates the treatment plans to the snowplow fleet's in-vehicle systems. The plans include routes, treatment required, material quantities, and so on. Both Michael and Bill's maintenance vehicles are dispatched to clear the snow and black ice. Their vehicles are automatically and continuously providing their locations, speeds, snowplow status, vehicle diagnostics, and status of deicing materials to help refine the response plans and treatment strategies.	Nick communicates the treatment plans to the snowplow fleet's in-vehicle systems. The plans include routes, treatment required, material quantities, and so on. His system also sends warnings of existing queues that have built up along treatment routes. Michael and Bill were dispatched to widen the roadway clearance area. Their vehicles use CACC to clear the roadway as a tandem. Due to the complex clearance operation, Michael's truck instructs him to assume control of the vehicle and perform the clearance activity manually.	—

—No data.

SCENARIO 4: WZM USE CASE (ON FREEWAY)

Maryland State Highway Authority, like other State agencies responsible for interstates, has a need to maintain the roadways, and this year a bridge deck on I–95 northbound, close to I–695 around Baltimore, needs to be repaired. The location for this fictitious work is shown in figure 9. The bridge deck will be replaced in one direction at a time, and each side will take 5 d to complete. To minimize the adverse impacts on busy I–95, the work is scheduled for the overnight hours only. The project is scheduled to get underway 4 weeks from now. The contractor is required to set up four portable variable message signs (VMSs), two of which will be placed upstream of the work zone in each direction. There is only one detour available for the northbound direction, where vehicles traveling toward Philadelphia, New York City, and Boston can take I–895.



Original Photo: © 2019 Google® (see Acknowledgments).

Figure 9. Map. WZM scenario location.

Table 45 summarizes the operational actions performed to address and resolve the work zone. Operational actions that a TMC or TMS must fulfill were identified in the Framework for WZM Use Case section. Table 45 relates these operational actions to the Cooperation Classes of vehicles on the freeway. The activities a TMS must respond to or initiate due to different SAE International Automation Levels are described in table 45. A scenario concept of WZM is shown in figure 10.

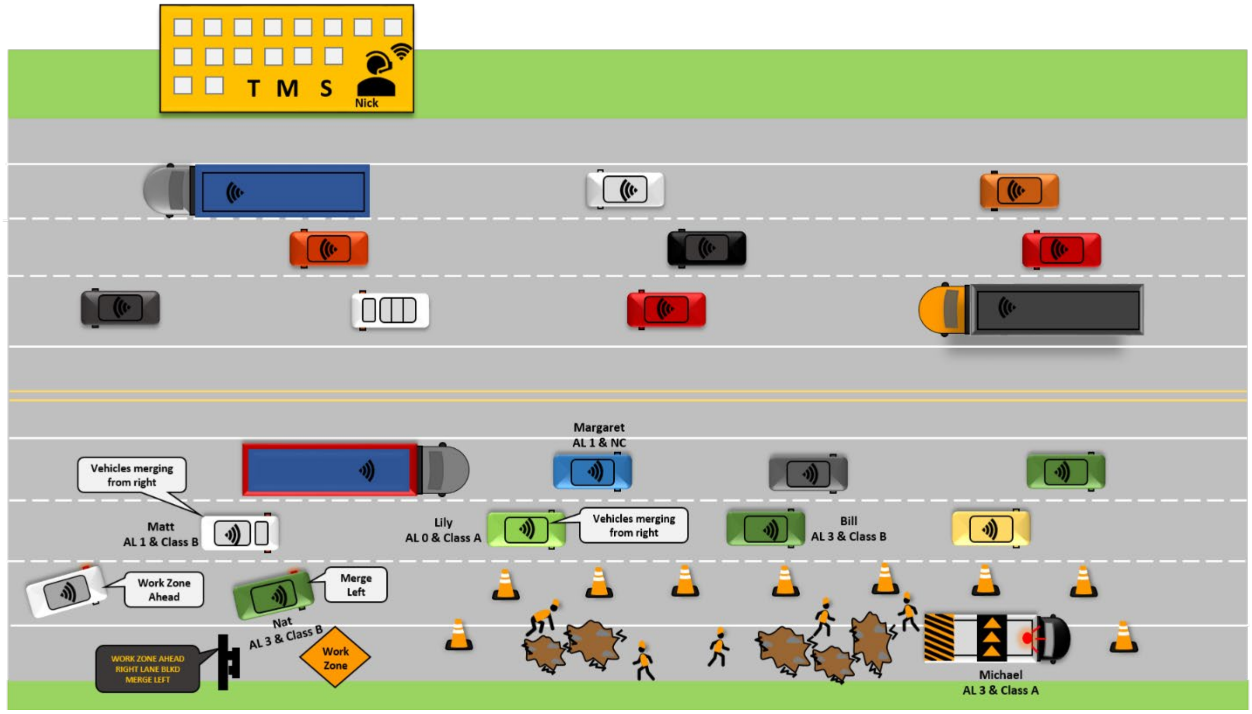
The following individuals play a role in this scenario:

- Nick is an operator in the Baltimore County, MD, TMC with primary responsibility for managing the work zone.
- Bill drives an Automation Level 3 truck with Cooperation Class B capabilities, meaning it can send and receive status and intention data. He is currently northbound on I–95 and upstream of the exit to I–895. He needs to go to Philadelphia to deliver his load.
- Margaret drives an Automation Level 1 vehicle with no cooperative automation capabilities, meaning it is not capable of sending or receiving data from any entity. She is also northbound on I–95 and on her way to work in downtown Baltimore.
- Lily drives a small Automation Level 0 vehicle with Cooperation Class A capabilities, meaning it can send status data, including information, such as *x*,*y* location; heading; and speed. She is on her way to visit her brother, Bob, in Ellicott City, MD.
- Matt drives an Automation Level 1 SUV with Cooperation Class B capabilities, meaning it can cooperate with surrounding CDA-equipped vehicles, roadside equipment, and back-office software via short- and long-range communications systems (e.g., DSRC and cellular). In addition to sending status data, the vehicle can send vehicle-related and environmental data and receive traveler information data from a TMS. Matt's vehicle also sends and receives mobility messages describing his and neighboring vehicles' future trajectory plans.
- Nat is driving an Automation Level 3 sedan with Cooperation Class B capabilities, meaning it can send and receive messages with similar content as Matt's, but Nat's vehicle can also negotiate with other, similarly equipped, nearby vehicles to coordinate their operations.
- Michael drives an Automation Level 3 construction truck with Cooperation Class A capabilities, meaning it can send and receive messages. It provides and receives data directly to and from his dispatch center and has on-board sensory capabilities that measure surface temperature, ambient temperature, and precipitation. Michael's truck delivers construction material to the work zone.

Work zones are normally planned events that can be prepared for in advance. For example, the portable VMSs are placed on the road about 1 week prior to the start of the work-zone activity to inform motorists of the upcoming work zone event. Other essential activities are executed following predefined SOPs, which are well-defined and assigned to responsible parties. The scenario response actions described in table 45 assume that all typical response actions are performed; it focuses on the enhanced actions made possible by CDA-equipped vehicle interactions.

Table 45 considers both the data and interactions sent to and received from TMSs and vehicles, as well as between vehicles (Cooperation Class B and Class C). A TMS may have multiple sources (e.g., traditional and non-TMS-to-vehicle options) for sending and receiving needed data.

Work-zone-activity data (e.g., response, site management, and traffic management) can come from agency-owned field devices, CCTVs, and third-party data providers who use crowdsourcing or prediction models based on AI and machine-learning algorithms, and so on.



Source: FHWA.
AL = Automation Level; Class = Cooperation Class; NC = no cooperation.

Figure 10. Illustration. WZM scenario.

Table 45. WZM scenario summary.

Number	TMS Operational Action	No Cooperative Automation	Cooperation Class A	Cooperation Class B	Cooperation Class C
1	Notify and advise	Following established SOPs developed for use within the agency and its partners, Nick, the Baltimore County, MD, TMC operator, informs the affected agencies of the planned work zone, its location, expected duration, lane closures, and detours. He can see the work zone via a nearby CCTV, which is helpful in monitoring the work progress, and so on. Nick also informs local radio and television stations to include notifications in their broadcasts beginning 1 w prior to activation of the work zone.	Nick, the Baltimore County, MD, TMC operator, receives and confirms the message broadcasted to vehicles of all Automation Levels near the work zone. The message contains work zone details, dynamic speed harmonization prior to the work zone, lane control information when available, applicable detour information, and any queue-warning information. The central software system also provides the following additional information: • For Automation Level 3 vehicles, the vehicle instructs the driver to assume control when approaching the work zone, though it is not clear whether this is a vehicle-internal decision based on location. • For Automation Level 4 and Automation Level 5 vehicles, the vehicle continuously receives updated geometric layout of the work zone site (MAP) including location of cones, construction personnel and vehicles, and so on. Michael and Bill's work vehicles broadcast data about the work zone location, extent, working hours, and so on, to other passing vehicles, such as Lily, Matt, and Nat's.	—	Nick's system has a network load-balancing algorithm that determines suitable detour routes and sends them to vehicles with Cooperation Class C capabilities approaching the work zone. Vehicles with Cooperation Class C capabilities, such as Nat's, receive these suggestions and provide an indication that the vehicle will follow the suggested detour.

Number	TMS Operational Action	No Cooperative Automation	Cooperation Class A	Cooperation Class B	Cooperation Class C
2	Respond	A week prior to activation of the work zone, Nick placed a continuous message on upstream VMSs in both directions to notify motorists of the upcoming work zone location, work zone active times, and lanes affected. Following the established SOPs, Nick warns motorists approaching the work zone site when the work zone is about to become active for the night work on the first day and all subsequent days. Messages are adjusted, as appropriate, between daytime, when the work zone is not active, and nighttime. Looking at the map-centric ATMS software package at his fingertips, Nick selects the nearest VMSs and places appropriate messages on them, warning approaching motorists upstream of the work zone site. The messages explain that all lanes in one direction are completely closed and all vehicles must merge into one lane in the northbound direction of the southbound lanes, while southbound traffic must merge into two lanes in the southbound direction. He also activates the highway advisory radio stations, which the Maryland State Highway Administration continues to maintain.	During this time, Nick receives and confirms a system-generated planned event (i.e., work zone) response plan, including broadcasting safe speeds when approaching the work zone site. Having previously readied plans with the Maryland State police to protect the work zone, a police cruiser is dispatched to the staging location at the beginning of the work zone and the TMC broadcasts vehicle staging location details for workers arriving at the work zone site, work zone crew supervisor contact information, and so on. Additionally, all vehicles (i.e., passenger, construction, and work zone protection police) continuously broadcast their location data and speeds to the TMC, regardless of Automation Level. Nick, the Baltimore County, MD, TMC operator, uses these data to update the notification messages and operational responses, as needed. Nick also receives updated information from other vehicles approaching and leaving the work zone for additional updates. Vehicles with Cooperation Class A capabilities, such as Bill, Matt, and Nat's, continuously broadcast data, such as location, speeds, and other vehicle- and environment-related data. These data can be used by a TMS or suitably equipped vehicles in the vicinity. Additionally, data about speed limits are sent to vehicles within the geofenced area and travel direction around the speed limits, which the vehicles are expected to implement in a harmonized manner to avoid rear-end crashes. Michael is dispatched to the work zone site in his suitably equipped Automation Level 3 vehicle. His vehicle has onboard sensory capabilities that allow for the measurement of surface temperature, ambient temperature, and precipitation—tonight the roadway is wet. Michael's vehicle continuously provides updated road weather information to the TMC while also sending data to his dispatch center, informing the garage technicians that the air pressure in his tires is low.	During this time, the TMC continuously sends updates of available detours. Automation Level 4 vehicles can receive and react to TMC-defined detours within geofenced areas and travel directions, allowing for limited network load-balancing, while Automation Level 5 vehicles can receive this information for the entire network. Vehicles with Cooperation Class B capabilities, such as Bill, Matt, and Nat's, broadcast detected traffic parameters associated with the work zone, which Nick's system picks up. Vehicles with Cooperation Class B capabilities also broadcast their intended trajectories to other vehicles in the vicinity.	Vehicles with Cooperation Class C capabilities, such as Nat's, negotiate with each other to determine a coordinated approach to work zones and provide acknowledgments. Nat's vehicle also negotiates with other vehicles with Cooperation Class C capabilities to cooperate in changing lanes, speeds, platooning parameters, and so on, as necessary to navigate past the work zone according to the temporary rules set up by the deployed geofences and travel direction.

Number	TMS Operational Action	No Cooperative Automation	Cooperation Class A	Cooperation Class B	Cooperation Class C
3	Manage site	Nick, the Baltimore County, MD, TMC operator, continues to monitor the work zone site via CCTV and informs other affected agencies. Onsite, the police officer and other staff perform their duties as they would without advanced vehicles.	During this time, all vehicles (i.e., passenger, trucks, and other construction), regardless of Automation Level, continuously broadcast their location data and speeds to the TMC. The continuous updates reveal that 10 percent of the vehicles followed the detour recommendations (via roadside intelligent transportation system field devices, VMS, and highway advisory radio, because vehicles with Cooperation Class A capabilities cannot receive data). Nick, the Baltimore County, MD, TMC operator, uses the data to obtain an accurate assessment of the traffic conditions around the work zone. He receives and confirms system-generated broadcasts of the work zone site, including detailed work vehicle locations and any changes to the site layout. When Michael, the construction vehicle operator driving an Automation Level 3 vehicle, arrives at the site, he receives detailed information about his staging location within the site from the TMC. Other work zone vehicles receive similar information for their staging locations. Michael's vehicle continues to broadcast location and speed data, as well as updated weather information, from its onboard sensory equipment to the TMC. Other CDA-equipped construction vehicles broadcast their arrival and activity data.	—	—

Number	TMS Operational Action	No Cooperative Automation	Cooperation Class A	Cooperation Class B	Cooperation Class C
4	Manage traffic	Nick, the Baltimore County, MD, TMC operator, continues to monitor the work zone site via CCTV and informs the other affected agencies. He also receives updates from the construction supervisor. Onsite, the police officer and other staff perform their duties as they would without advanced vehicles.	All vehicles (i.e., passenger and construction), regardless of Automation Level, continuously broadcast their location data and speeds to the TMC. Nick, the Baltimore County, MD, TMC operator, continues to receive and confirm system-generated broadcasts about the work zones, including detours, detailed construction vehicle locations, work zone activities affecting approaching vehicles, planned end-of-work-zone activities for today, weather changes, status of queues that are building up, travel conditions around work zones, and changes to the site layout. The central software system provides the following additional information: • For Automation Level 1 and Automation Level 2 vehicles, create and broadcast updates of geometric layout of the work zone (MAP); provide additional details regarding locations of cones for merging, layout of work zone end, and how to navigate it, which is important because lane delineations may no longer be valid. • For Automation Level 3 vehicles, create and broadcast notification to vehicles to inform drivers to assume control when approaching the work zone location, though it is not clear whether this is a vehicle-internal decision based on location. • For Automation Level 4 and Automation Level 5 vehicles, create and broadcast geometric layout of the work zone site, including locations of cones, construction vehicles, and so on.	Nick's system provides updates to the geographic layout of the work zone as soon as they are made available, including the location of cones. Vehicles with Cooperation Class B capabilities broadcast their intentions and observe those of neighboring vehicles. They develop trajectories to maneuver within the traffic stream that they understand from adjacent vehicle plans. Maneuvering is performed in accordance with rules established by deployed geofences and travel direction.	—

Number	TMS Operational Action	No Cooperative Automation	Cooperation Class A	Cooperation Class B	Cooperation Class C
5	Clear and terminate event	Nick, the Baltimore County, MD, TMC operator, continues to monitor the work zone site via CCTV and informs other affected agencies. He also receives updates from the construction supervisor who informed him that the construction vehicles are being removed from the site and construction debris is being picked up. Onsite, the police officer and other onsite staff perform their duties as they would without advanced vehicles.	All vehicles (i.e., passenger and construction), regardless of Automation Level, continuously broadcast their location data and speeds to the TMC. Nick, the Baltimore County, MD, TMC operator, continues to receive and confirm system-generated broadcasts about the work zone, including the status of construction debris removal from affected roadway lanes, detours, detailed construction vehicle locations, work zone activities affecting approaching vehicles, estimated end-of-work-zone activities for the day, weather changes, any queues, the current travel conditions around the work zone, and changes to the site layout. The central software system also provides the following additional information: • For Automation Level 3 vehicles, update and broadcast notification to vehicles to inform drivers that vehicles can resume control after they have passed the work zone, though it is not clear whether this is a vehicle-internal decision based on location. • For Automation Level 4 and Automation Level 5 vehicles, update and broadcast the geometric layout of the work zone, including locations of cones, construction vehicles, and so on.	Vehicles with Cooperation Class B capabilities broadcast their intentions and observe those of neighboring vehicles. They develop trajectories to politely maneuver within the traffic stream that they understand from adjacent vehicle plans. Maneuvering is performed in accordance with rules established by deployed geofences and travel direction.	—
6	Recover	Nick, the Baltimore County, MD, TMC operator, receives a final update from the construction supervisor stating that all construction vehicles left the work zone, which he confirms via CCTV. Following established SOPs, he notifies affected agencies of the end of the work zone for the day, removes the work zone messages from the VMS and highway advisory radio, and prepares the daily work zone report for his supervisor for later analysis and evaluation.	All vehicles (i.e., passenger and construction), regardless of the Automation Level, continuously broadcast their location data and speeds to the TMC. After determining that the work zone is closed for the day and all lanes are reopened, Nick, the Baltimore County, MD, TMC operator, receives and confirms a system-generated broadcast announcing that all lanes are accessible. The central software system also provides the following additional information: • For Automation Level 3 vehicles, update and broadcast the notification to vehicles to inform drivers that the vehicles can resume control, though it is not clear whether this is a vehicle-internal decision based on location. • For Automation Level 4 and Automation Level 5 vehicles, update and broadcast the geometric layout with all lanes open.	Vehicles with Cooperation Class B capabilities broadcast their intentions and observe those of neighboring vehicles. They develop trajectories to politely maneuver within the traffic stream that they understand from adjacent vehicle plans. Maneuvering is performed in accordance with rules established by deployed geofences and travel direction.	Vehicles with Cooperation Class C capabilities negotiate with each other to cooperate in reentering the newly opened lanes, changing lanes elsewhere, recovering speeds, reforming platoons, and so on, as necessary, to pass the former work site.

—No data.
MAP = map data.

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