CAMP LLC

Vehicle-to-Infrastructure 2 (V2I-2) Consortium

Vehicle-to-Infrastructure (V2I) Program

V2I Safety Applications

Event Driven Configurable Messaging (EDCM) Concept of Operations – Version 1.6

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Executive Summary

This report is a Concept of Operations that describes a conceptual system for Event Driven Configurable Messaging (EDCM), including envisioned message structures and system elements that will support communication flows and message management for a variety of event scenarios. It is written from a variety of perspectives to facilitate understanding of how EDCM may impact both stakeholders and systems. The EDCM Project is conducted by the Vehicle-to-Infrastructure (V2I) 2 (V2I-2) Consortium. The project is sponsored by the Federal Highway Administration (FHWA) through Cooperative Agreement No. DTFH6114H00002.

EDCM is a *flexible messaging approach* between connected vehicles and Infrastructure Owner Operators (IOO) Traffic Management Centers (TMC) that leverages existing connected vehicle infrastructure and communications to identify events and road conditions that potentially impede the safety and mobility of the traveling public. The EDCM System includes this messaging approach and supporting software for exchanging information between the TMC and EDCM-enabled vehicles, aggregating information with other data, analyzing that data, and determining the situation. The EDCM System operates within the larger EDCM environment which includes supporting connected vehicle infrastructure, connected vehicles, and other features like security protocols and privacy in the TMC and region that are required for EDCM to function but are not detailed in this document.

EDCM allows for forward and backward compatibility that reflects unforeseen changes in vehicle technologies, can easily be adapted for new use cases, and incorporates a flexible messaging strategy for the following three steps:

1. Transmission of Query Messages (QMs) generated using a messaging language from the TMC to connected vehicles with EDCM capabilities using Roadside Units (RSUs) or the cloud networks via available and preferred short-, medium-, or long-range wireless communications to request feedback on current conditions either on periodic bases or instance based for a selected geofenced area.
2. Optional response via available and preferred wireless communications from vehicles receiving this message with a Response Message (RM) that contains vehicle status data, if:
    a. Warranted by the current conditions
    b. Desired given available data and computing resources
    c. The vehicle owner has opted in to providing vehicle status data
3. TMC aggregation and processing of received RMs to take appropriate actions for identified events which may include the transmission of additional connected application-specific Road Safety Messages (RSMs) to all connected vehicles.

This document describes the current situation and needs for EDCM, the proposed EDCM concept, anticipated roadway conditions and vehicle types for EDCM, and operational concepts that describe distinct perspectives of each element of the human and non-human EDCM System and EDCM environment.

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List of Acronyms

Acronym	Description
ABS	Anti-lock Braking System
ACC	Adaptive Cruise Control
AMCD	Advanced Messaging Concept Development
ATIS	Advanced Traveler Information System
ATM	Active Traffic Management
ATMS	Advanced Traffic Management System
BMM	Basic Mobility Message
BSM	Basic Safety Message
CADS	Cooperative Automated Driving System
CAMP	Crash Avoidance Metrics Partners LLC
CCTV	Closed Circuit Television
CV PFS	Connected Vehicle Pooled Fund Study
DMS	Dynamic Message Sign
DSRC	Dedicated Short-range Communication
ESC	Electronic Stability Control
EDCM	Event-Driven Configurable Messaging
FHWA	Federal Highway Administration
ID	Identifier
IOO	Infrastructure Owner Operators
ITS	Intelligent Transportation Systems
MDSS	Maintenance Decision Support System
MMS	Maintenance Management System
OBU	On-Board Unit
OEM	Original Equipment Manufacturer
PDM	Probe Data Message
QA/QW	Queue Advisory / Queue Warning
QM	Query Messages

Acronym	Description
RM	Response Message
RSM	Road Safety Message
RSU	Roadside Unit
RWIS	Road Weather Information Stations
TCS	Traction Control System
TMC	Transportation Management Center
TOC	Transportation Operations Center
TSMO	Transportation Systems Management and Operations
USDOT	United States Department of Transportation
V2I	Vehicle-to-Infrastructure
V2I-2	Vehicle-to-Infrastructure Consortium 2
V2V	Vehicle-to-Vehicle
VTTI	Virginia Tech Transportation Institute
XML	eXtensible Markup Language

1 Introduction

1.1 Background

Events routinely occur on roadways that can impact travelers' safety and disrupt the flow of traffic, including recurring congestion during peak hours, incidents, severe weather, and planned and unplanned maintenance and work zones. Infrastructure owner operators (IOOs) strive to identify and address these events in an expedient manner to minimize disruption to the transportation network. The operations activities to address these events are typically conducted in a Transportation Management Center (TMC), which is sometimes referred to as a Transportation Operations Center (TOC), or by IOO operations staff, hereafter referred to as TMC. For example, IOO staff who identify an event on traffic cameras will dispatch emergency responders or incident response teams and then post messages on available pre-trip and en route traveler information mechanisms to alert travelers. Travelers who are aware of an event may choose to change the time or route of their trip to avoid the congested area. En route travelers will use the information to increase their awareness and reduce the risk of unexpectedly reaching a sudden slowdown at the back of a queue that would otherwise increase the chances of a secondary incident or crash.

As the industry transitions towards a combination of human drivers and machine-driven Cooperative Automated Driving Systems (CADS), it can also benefit from data describing congestion, weather, pavement irregularities, and other events that will enable vehicle operators, whether human or machine, to alter routes or travel speeds, or take other precautions.

Additionally, the roadway geometries, surface irregularities, and site distances associated with some roadway segments create situations where IOOs might benefit by receiving information from vehicles on these segments (e.g., times and locations where hard braking occurs or excessive vertical movements of the vehicles) to consider infrastructure changes or maintenance activities. For these considerations, the IOOs that benefit from the data may extend beyond TMC staff to include maintenance, planning, or construction.

The **Event-Driven Configurable Messaging (EDCM)** system provides an opportunity for both IOOs and vehicle operators to have increased situational awareness in a timelier manner than the current state in order to reduce the risk of crashes. This proposed concept would allow IOOs to selectively query information regarding current conditions from connected vehicles that are enabled with EDCM capabilities in specified areas. That is, EDCM provides a mechanism to collect data from a sample of EDCM-enabled vehicles to understand current conditions, generating a smaller, more manageable volume of data to process than what would be collected via Basic Safety Messages (BSMs), as well as the ability to collect data not contained in a BSM. The EDCM vehicle response could be used by the IOO to identify the location and/or gather real-time condition information about various roadway network metrics such as:

- Queues caused by recurring congestion or other events
- Incidents
- Work zones
- Adverse road weather conditions

- Pavement irregularities that require maintenance and/or are problematic to CADS
- Improvable roadway sections in which vehicles are not traversing as intended (e.g., excessive curve speed due to, for example, missing signage)

With this increased situational awareness, the IOO would be able to notify emergency responders, an incident response team, towing company, road maintenance, or winter maintenance staff, as needed to address the identified event. The IOO could leverage traditional traveler information mechanisms and transmit messages to all connected vehicles to provide advanced notice of the event to the vehicle operator. This advanced notice would potentially allow vehicle operators an opportunity to navigate to an alternate route to avoid the event or to be aware of an event that could otherwise increase crash risks for vehicle operators or present a challenging situation to CADS. In addition, the EDCM messaging structure may be used for more strategic transportation network monitoring and response. Engineering divisions may use the EDCM to acquire information about how vehicles are crossing certain roadway segments to assist with roadway design evaluation and improvement strategies.

This EDCM effort builds on USDOT-sponsored research under the **Advanced Messaging Concept Development (AMCD) Project**[1] that was conducted by Crash Avoidance Metrics Partners LLC Vehicle-to-Infrastructure (V2I) Consortium, which evaluated "the ability of connected vehicles to generate, and infrastructure to collect, BSM, Probe Data Message (PDM), and Basic Mobility Message (BMM) alternatives using both cellular and Dedicated Short-range Communication (DSRC), employing basic message control strategies in real-world driving conditions for non-safety-critical applications." Findings from the AMCD research included the following recommendations for next steps:

- ***Enhanced flexible messages*** to provide a more effective mechanism for infrastructure applications to query data from vehicles with the aim of improving roadway operations. This can be accomplished by migrating to condition-based messaging that will avoid On-board Unit (OBU) overloading, integrate priorities, optimize communication modes, and allow for more sophisticated geofencing for backward and forward compatibility as future needs arise.

- ***Develop applications*** that address specific roadway operational challenges, show the versatility of a flexible message structure to support a wide range of applications, provide context for an evaluation of performance, and demonstrate the feasibility of the V2I message. Recommended examples were: Traffic Behavior Investigation Tool, Roadway Hazard Identification, Incident Detection, and Infrastructure Design Assessment.

- ***Integrate applications into the TMC environment*** to assess the value of real-time, vehicle-dynamics data in improving infrastructure operations and support the conduct of the following analyses:
  - Evaluate the actions executed with roadway information and determine if they enhance existing operating procedures.

[1] Advanced Messaging Concept Development (AMCD) Project Vehicle-to-Infrastructure Program Final Report. FHWA-JPO-18- 620. Federal Highway Administration Headquarters. June 30, 2017.

- Verify compatibility of the new information and systems/displays with existing investments and infrastructure.
- Compile operational improvement data to evaluate the value proposition for both the roadside owner/operator and vehicle original equipment manufacturers (OEMs).

1.2 Purpose of EDCM

EDCM is a *flexible messaging approach* between connected vehicles and IOO TMCs that leverages existing connected vehicle infrastructure and communications to identify events and road conditions that potentially impede the safety and mobility of the traveling public. The EDCM System includes this messaging approach and supporting software for exchanging information between the TMC and EDCM-enabled vehicles, aggregating information with other data, analyzing that data, and determining the situation. The EDCM System operates within the larger EDCM environment which includes supporting connected vehicle infrastructure, connected vehicles, and other features like security protocols and privacy in the TMC and region that are required for EDCM to function but are not detailed in this document.

EDCM represents an evolved, new generation approach that builds on the AMCD lessons learned and project recommendations. This evolution to EDCM is important to allow for forward and backward compatibility that reflects unforeseen changes in vehicle technologies, can easily be adapted for new use cases, and incorporates a flexible messaging strategy for the following three steps:

1. Transmission of Query Messages (QMs) generated using a messaging language from the TMC to connected vehicles with EDCM capabilities using Roadside Units (RSUs) or the cloud networks via available and preferred short-, medium-, or long-range wireless communications to request feedback on current conditions either on periodic bases or instance based for a selected geofenced area.

2. Optional response via available and preferred wireless communications from vehicles receiving this message with a Response Message (RM) that contains vehicle status data, if:

    a. Warranted by the current conditions
    b. Desired given available data and computing resources
    c. The vehicle owner has opted in to providing vehicle status data

3. TMC aggregation and processing of received RMs to take appropriate actions for identified events which may include the transmission of additional connected application-specific Road Safety Messages (RSMs) to all connected vehicles.

The primary advantage of the EDCM approach is the ability of IOOs to selectively query and receive samples of data from a random selection of equipped vehicles. This results in a smaller, targeted, and more manageable volume of data, allowing for IOOs to employ simpler data processing requirements to understand current road conditions. By comparison, BSMs are generated and collected on a continuous basis and not targeted to regions of interest and conditions, which would require additional data storage, communications, and processing capabilities. It is

envisioned that EDCM will supplement and enhance existing IOO systems. The IOOs currently develop and implement Transportation Systems Management and Operations (TSMO) plans and processes to continually improve current practices. For example, IOOs strategically deploy a variety of Intelligent Transportation Systems (ITS) like Closed-circuit Television (CCTV) cameras, sensors and detectors, and Road Weather Information Stations (RWIS), as well as vehicle data sources to monitor traffic and road weather conditions. This supports IOOs in identifying queuing and events that impact traffic that can then be reported to the traveling public via Dynamic Message Signs (DMS) and Advanced Traveler Information Systems (ATIS) like 511 phone service, traveler information websites, and mobile apps. EDCM will provide additional, more accurate, and more precise data points on the status of road and traffic conditions to substantively increase IOO situational awareness throughout the transportation network.

It is envisioned the data collected using EDCM approaches will also support a variety of vehicle systems and safety-related features as the data collected is processed into information and disseminated to the vehicles through RSMs. Additionally, EDCM provides the potential for IOOs to enhance design processes by generating off-line assessments for potential design changes as well as winter and road maintenance response activities through increased winter road weather condition reporting and maintenance reporting, respectively.

1.3 Document Purpose and Overview

This Concept of Operations document includes descriptions of a conceptual EDCM System, envisioned message structures, and system elements that will support communication flows and message management for the EDCM concept for a variety of event scenarios. It is written from a variety of perspectives to facilitate the understanding of how EDCM may impact both stakeholders and systems. The intended audience includes IOOs (including TMC operators, planners, maintenance, and other IOO areas), and OEMs of connected vehicles and automation systems to inform development and testing of the proposed EDCM concept.

Following this introduction, this document is organized into the following chapters:

Chapter 2. Current Situation and Needs - Describes the current system and associated challenges, as well as identified stakeholders and needs that would be addressed by the proposed EDCM concept.

Chapter 3. Proposed EDCM Concept - Presents an overview of the proposed EDCM concept, a vision for nationwide usage of EDCM, details about the envisioned EDCM environment, and EDCM use cases.

Chapter 4. Conditions - Describes the anticipated roadway conditions and vehicle types and conditions for both the initial EDCM System concept and an eventual, fully developed EDCM System.

Chapter 5. Operational Concepts - Description of distinct perspectives of each element of the human and non-human EDCM System and EDCM environment including the perspectives

of vehicles, vehicle operators, infrastructure, data sources, IOO stakeholders, and Advanced Traffic Management Systems (ATMS) and ATIS.

This document complements and supports other related documents and resources, including:

- Stakeholder engagement conducted as part of this effort served as input for this document, particularly the identification of the current situation, stakeholders, and user needs.
- EDCM architecture documentation related to this effort includes communications architecture design and development, vehicle hardware and software architecture design and development, and infrastructure (TMC) back office interface and information process to support EDCM and applications.
- Support for development of a Queue Advisory/Queue Warning (QA/QW) System Concept of Operations as part of a related effort led by the Connected Vehicle Pooled Fund Study (CV PFS).

The EDCM Project is conducted by the Vehicle-to-Infrastructure (V2I) 2 (V2I-2) Consortium. The project is sponsored by the Federal Highway Administration (FHWA) through Cooperative Agreement No. DTFH6114H00002.

2 Current Situation and Needs

2.1 Current System and Challenges

The IOOs are constantly challenged to identify and respond to events occurring on the transportation network in a timely manner. Ideally, IOOs would identify events and notify the traveling public as soon as possible after the event occurs. Since immediate identification of events is not practically feasible, the traveling public is challenged with congestion and exposed to a higher risk for crashes due to adverse weather conditions or sudden drops in speed caused by queuing.

Virginia Tech Transportation Institute (VTTI) led a series of outreach and stakeholder engagement meetings in four diverse locations across the state of Virginia in 2019. The following use cases were discussed as exemplary scenarios for where EDCM could support applications to help address some of these challenges faced by IOOs and the traveling public.

- **Traffic Condition** - Applications that provide information to the TMC from connected vehicles about the level of traffic congestion (traffic flow), such as free flow (near posted speed limit), moderately congested, heavily congested, or stop-and-go (crawling) conditions to monitor planned events or identify unplanned events.
    - **Queue Advisory and Queue Warning (QA/QW)** - An application that provides information to the TMC from connected vehicles that can be used to identify traffic conditions that correspond to a traffic queue.
    - **Work Zone Warning** – An application that provides information about the conditions that exist in a work zone to vehicles that are approaching the work zone. This application provides approaching vehicles with information about work zone activities that may result in safety impacts for the vehicle, such as obstructions in the vehicle's travel lane, lane closures, lane shifts, speed reductions or vehicles entering/exiting the work zone.
    - **Incident Detection** – An application that identifies and notifies the TMC of conditions that could impact safety or mobility, such as:
        - **High Dynamic Maneuver** – An example of an incident detection application that identifies and notifies the TMC of situations where a vehicle has experienced a sudden maneuver that is possibly indicative of avoiding debris on the roadway or other obstructions that might cause or be the result of a crash or other incident.
        - **Crash** – an example of an incident detection application that identifies and notifies the TMC of a vehicle experiencing movements that are likely to indicate a crash has occurred (e.g., sudden delta velocity).
- **Roadway and Road Surface Management** – An application that provides information to the TMC from connected vehicles that could indicate roadway segments that IOOs may monitor to assess geometries or surface conditions.

- **Pothole or Other Roadway Surface Irregularities** - Example of roadway and road surface management application that identifies and notifies the TMC of a potential roadway issue that is identified by a vertical offset relative to the road surface, e.g., pothole, that could require a maintenance response.
- **Atypical Roadway Sections** - Example of roadway and road surface management application that identifies and notifies the TMC of specific locations where vehicle operators of connected vehicles routinely engage hard braking, e.g., on a sharp curve. This may help to identify roadway segments where design modifications like a change in roadway geometry, or the addition of signage or ITS could improve safety.
- **Engineering Analysis** - Example of roadway and road surface management application involving the collection of data from connected vehicles to provide historic information that can be used to evaluate general roadway design that impacts mobility and safety on roadways.

- **Weather Event** - Application that identifies and notifies the TMC of a potential road weather event that could cause safety or mobility issues, including ice or water on the roadway or heavy rain.

Overall, participants in each of the four stakeholder engagement meetings, representing both urban and rural areas, recognized the value for each of these use cases. The greatest emphasis and priority use cases were for those involving queues, work zones and incident detection. Additional use cases identified by participants included provision of route information for detours or diversion, identification of wrong-way drivers, truck parking availability, over height truck detection in advance of low-clearance bridges or tunnels, law enforcement presence, and monitoring during hurricane evacuation.

2.2 EDCM Stakeholders

The EDCM stakeholders are defined as the humans and non-humans that will benefit from and/or interact with the EDCM System. The stakeholders' needs are documented in Section 2.3, and operational concepts are used to describe each stakeholder's interaction with the EDCM System.

EDCM Stakeholders are expected to include the following:

Vehicle Operators While human drivers have traditionally been the individuals responsible for operating the vehicle, the introduction of automation broadens the definition of vehicle operators. Therefore, vehicle operators refer both to the human drivers and machines (vehicle automation) that operate the vehicle. Vehicle operators have needs for safety and mobility as the vehicle is operational. While the EDCM System may not directly address these needs, the EDCM System will likely support on-board applications or infrastructure-based systems (e.g., dynamic message signs, traveler information systems, etc.) that directly address vehicle operators' needs. Throughout this document, the vehicle operator stakeholder group may be described as four types of operators:

- *Operators of Non-EDCM-enabled Vehicles* - These would include operators of vehicles that are not enabled to participate in EDCM exchanges.
- *Operators of Non-EDCM-enabled Connected Vehicles* - These would include operators of vehicles that are not enabled to participate in EDCM exchanges but have connections to communicate with other vehicles (Vehicle-to-Vehicle (V2V)) or the infrastructure (V2I), and, therefore could receive information generated from EDCM exchanges between the IOOs and enabled vehicles, as the end information is sent in a format (e.g., RSM) that non-EDCM-enabled vehicles could ingest.
- *Operators of EDCM-enabled Vehicles* - Including operators of vehicles that are enabled to participate in EDCM exchanges and appropriate on-board applications. These vehicles also receive end information in the form of RSMs.
- *Operators of EDCM-enabled Expanded Role Vehicles* - Defined as those operators of vehicles with additional capabilities that may include:
  - Specially equipped sensors to capture more data than consumer vehicles.
  - Features to use data from the EDCM System differently than the traveling public (e.g., to adjust winter maintenance roadway treatments such as sand application rates or use of snowplows).

Table 1 illustrates the data communications and visual exchanges of data and information in order to explain the differences between the use of QM/RM communications and RSM communications.

Table 1: Examples of QM/RM, RSM, and DMS Use for Communicating

	Data Communication		Visual
	QM/RM	RSM	DMS/ATMS
Connected Vehicle EDCM Enabled	Yes	Yes	N/A
Connected Vehicle Non-EDCM Enabled	No	Yes	N/A
Non-Connected Vehicle	No	No	N/A
Vehicle Operator View of Information	No	No	Yes

Infrastructure Operators

Transportation operations staff ('infrastructure operators' or 'operators') perform critical roles in managing traffic, dispatching maintenance or incident response, and informing travelers of events that occur on the roadway. Operators generally must respond quickly to real-time events and information. Operators often work in a TMC, which is sometimes referred to as a TOC, but may perform this role remotely through virtual centers. In order to perform these roles, operators have needs for data and information. Operators will also perform an active role in the overall EDCM System (e.g.,

confirmation of events, decision-making, etc.) and will have needs for automated processing of data.

Administrators These will include IOO staff responsible for administering the EDCM System. This will typically differ from the real-time interactions that operators will have with the infrastructure, but for some IOOs, operators and administrators, it may be the same individual(s). Administrators will have needs and roles related to their responsibilities to develop, configure, and update the queries, managing compatibility with other IOO systems, especially during software updates or upgrades, and other actions to ensure the operators interaction with the EDCM System is effective.

Other IOO Users The generic term "Other IOO Users" represents various individuals or groups within the IOO that have needs that may partially or wholly be addressed by the data and information generated by EDCM. These may include:

- Planners or designers that may use the data generated for non-real-time activities to improve the safety and mobility of the network.
- Maintenance and operations staff that may use the data for real-time management, e.g., using a Maintenance Management System (MMS) or Maintenance Decision Support Systems (MDSS).

2.3 Stakeholder Needs

User needs for each stakeholder group are presented below. These needs have been developed based on content in the AMCD Project Final Report and reinforced or expanded upon as part of the VTTI outreach efforts (described earlier) for this Project, as described above.

2.3.1 Vehicle Operator Needs

Vehicle Operator Need #1: Vehicle Operators need to be alerted to situations that may impact the safety or mobility of their trips. Situations may include crashes, adverse weather, work zones, incidents, queues, and other that may impact normal traffic flow (e.g., gawkers).

Vehicle Operator Need #2: Vehicle Operators need information/alerts to be relevant and timely to take appropriate decision/action, given the dynamic nature of events.

Vehicle Operator Need #3: Vehicle Operators that are human drivers need to maintain their attention on the driving task and avoid irrelevant or untimely information.

Vehicle Operator Need #4: Vehicle Operators need on-board system communicating with the infrastructure to be universal nationwide, and not require updates or configuration changes when traveling outside their home area.

2.3.2 Infrastructure Operator Needs

Infrastructure Operator Need #1: In order to address roadway travelers' needs for timely, accurate, comprehensive information, Infrastructure Operators need additional data about traffic conditions on the road (e.g., weather, congestion, queues) to supplement existing data and event collection.

Infrastructure Operator Need #2: Operators and managers need to be able to configure and prioritize data queries and responses in order to focus event data collection on specific geographic areas, times of day, or dynamic conditions (e.g., adverse weather or local venue based). For example, operators may wish to query weather impacts on vehicle traction during a range of temperatures and/or combination with precipitation, ignoring input at other times.

Infrastructure Operator Need #3: Operators need data collection, assembly, and dissemination to be automated and require minimal operator involvement, other than configuration or triggering activation, to reduce workload and improve operator ability to respond to traffic conditions.

Infrastructure Operator Need #4: To supplement existing traveler information and traffic management tools and approaches in order to enhance the performance of the transportation network, Infrastructure Operators need a mechanism to communicate information directly to the vehicles to enable the vehicle to determine a course of action or inaction to support the vehicle operator.

Infrastructure Operator Need #5: Operators need tools, strategies, and applications, including those that leverage vehicle-to-infrastructure communications, to dynamically manage the transportation network in order to increase capacity and improve system performance.

2.3.3 Administrator Needs

Administrator Need #1: Administrators responsible for configuring V2I information exchange systems to collect data need a standardized approach to messages and data exchange to reach all participating vehicles.

2.3.4 Other IOO User Needs

Other IOO Need #1: Other groups within state and local IOOs need supplementary data about conditions, vehicle movements, or actions they are not able to detect or measure otherwise in timely manner

3 Proposed EDCM Concept

3.1 Overview of Event Driven Configurable Messaging (EDCM)

As described in earlier sections, both vehicle operators and IOOs have needs for increased information about events and traffic conditions on the roadways. Connected vehicles that are capable of information exchange offer opportunities to increase situational awareness and reporting of information to IOOs. Similarly, connected vehicles that receive specific condition (e.g., queue) relevant messages that are generated by EDCM System exchanges offer opportunities to better inform vehicles of downstream conditions over traditional infrastructure-based approaches through the potential use of in-vehicle alerts to vehicle operators or CADS control movements. On the other hand, if BSMs alone are used for continuous transmission of vehicle data from all regions, it could create an inefficient situation where volumes of messages would be transmitted but may not be used effectively. For example, on a clear summer day when the temperature is 70 degrees, IOOs have no need to receive continuous BSMs from every connected vehicle reporting the external temperature and status of anti-lock braking systems (ABS) and Traction Control Systems (TCS). However, temperature and ABS/TCS status data would be beneficial during times when temperature near freezing is just beginning and particularly on bridges or other weather susceptible roadway sections. Similarly, traffic queues may form on any highway at any time, and some locations are more prone to queues. Therefore, IOOs would benefit more from continuous reports of vehicle speeds in selected 'hot spots' where queues are most likely to form.

For these reasons, the EDCM System would operate a flexible messaging scheme, with the ability to dynamically adjust a two-way data exchange between EDCM-enabled vehicles and infrastructure systems (typically operated by TMCs). The EDCM System queries and gathers targeted samples of data from EDCM-enabled vehicles to facilitate simplified data gathering from region of interest and processing requirements. The following high-level examples illustrate the concept:

- IOOs may define geofenced areas and transmit queries to all enabled vehicles within the area to report one or more selected parameters (e.g., speed) at requested frequencies. When in the geofenced area, EDCM-enabled vehicles would reply to received queries with the queried data.
- IOOs may transmit queries during specific conditions (e.g., when temperature or precipitation thresholds are met) for specific geofenced areas. EDCM-enabled vehicles would reply to received queries with the requested information when the specific condition(s) is/are met or by a heartbeat message that the vehicle is within a geofenced area for the IOO to know that the query was received but the trigger condition(s) is/are not met.
- IOOs may transmit queries to all enabled vehicles during all time periods to report situations where hard braking occurs, as a possible indicator of crashes or queues forming. EDCM-enabled vehicles will only respond to these queries if they encounter braking that exceeds the defined threshold. The response of a hard-braking event may be combined with

other data by the infrastructure operator to determine if an anomaly of interest is occurring. The following sections present more details on the EDCM System concept, use cases, and operational concepts.

3.2 What EDCM Is and What EDCM Is Not

What EDCM Is:

An EDCM System provides a flexible messaging structure that facilitates a dynamically-adjustable two-way data exchange between the TMC and enabled connected vehicles. It consists of a wireless communication subsystem for data exchange and an information processing subsystem for generating actionable end information.

What EDCM Is Not:

There are several supporting elements to an EDCM System. These are not considered EDCM and are expected to be deployed independently and are not specifically to support an EDCM System. These elements include vehicle sensors, vehicle systems, IOO systems for data entry, IOO systems for information analysis and use, vehicle communications, and IOO communications.

IOOs can use EDCM collected data in concert with other data sources to process and identify traffic conditions that impede safety and/or disturb mobility on the roadway network in order to take appropriate action. However, the IOO actions or the systems used to respond to conditions detected are also not considered EDCM.

Use of EDCM:

The IOO may use the EDCM System to query vehicles about a variety of data elements to improve situational awareness by:

- Monitoring traffic conditions to identify queues on segments known to experience recurring congestion or have a work zone
- Identifying incidents that have occurred, which may cause queues to form
- Identifying conditions that may warrant improved roadway geometry, additional warning signage, or maintenance needs such as a pothole
- Monitoring adverse road weather conditions

IOOs would subsequently use information received from EDCM-enabled vehicles combined with other external third-party data to take appropriate action, as shown in Figure 1, which may include:

- Disseminating warnings or messages via traditional ATMS/ATIS mechanisms
- Disseminating application specific RSMs to connected vehicles (either manually driven or operated by automated driving systems) via roadside units or network communications
- Dispatching emergency responders, law enforcement, and/or incident response team for an identified incident
- Dispatching maintenance staff, e.g., to install additional warning signage or fix potholes

- Informing IOO planning and design about the need to modify a roadway segment or future roadway designs
- Dispatching winter maintenance crews

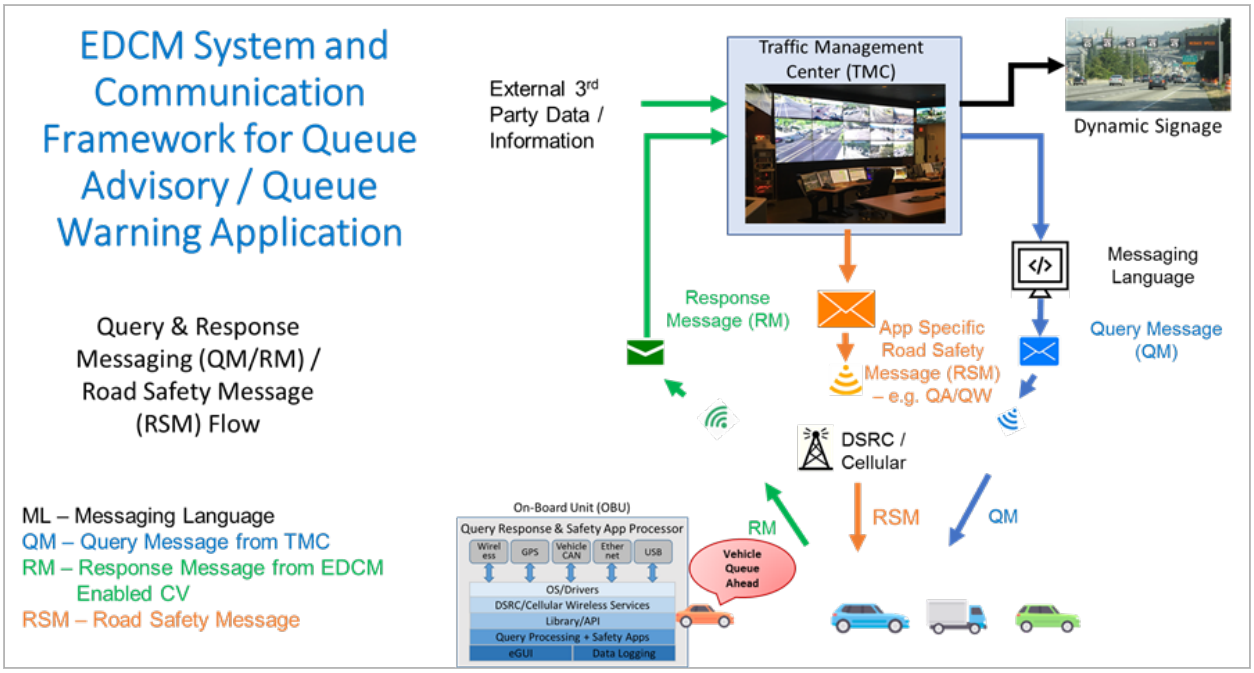

Figure 1: EDCM System and Communication Framework for QA/QW Application

To the extent possible, IOOs would likely configure the EDCM System to automatically generate and issue queries to reduce operator workload. The EDCM System may selectively query data from a random selection of enabled vehicles resulting in a smaller, targeted, and more manageable volume of data. However, operators would also be able to issue queries, as needed.

Queries are expected to vary in several ways, as appropriate:

- Location specific
  - Entire roadway network
  - Geofenced area
  - Vehicles traveling in specific direction for specified distance
- EDCM-enabled vehicle receiving a query
  - All vehicles
  - Subset of vehicles to reduce volume of data, i.e., a sample of vehicles
  - Selected types of vehicle, e.g., snowplows or other fleet vehicles
- Response expectation
  - On-demand queries to monitor traffic conditions result in an immediate response, e.g., when an IOO suspects conditions might cause incidents or inclement weather
  - Continuous queries generate a response only when current conditions trigger a response, e.g., sudden deceleration that might indicate a traffic backup and potential of forming a queue.

The EDCM System approach is premised on the presence of existing vehicle technologies, systems, communications, and devices. These elements are expected to be deployed in support of other connected vehicle applications and CADS, and, thus, available to be leveraged for two-way information exchange for the EDCM System. Likewise, the EDCM System is envisioned to streamline data collection processes of IOOs that provides specific data at desired granularity and frequency, rather than relying on processing all continuously collected BSM data. As such, the EDCM System alleviates the need for continuous collection of data and enables IOOs to employ simpler data processing and analysis to understand current road conditions and future needs.

The operational environment of the TMC includes a variety of IOO resources, including TMC resources and software, infrastructure and ITS, fleet vehicles, and communications infrastructure. Information from the EDCM System informs how these IOO resources are used to better manage and maintain the transportation network. For example, the TMC may post warning messages to ITS devices in the field like DMS if a queue or incident is detected and a safety service patrol is dispatched to the incident location.

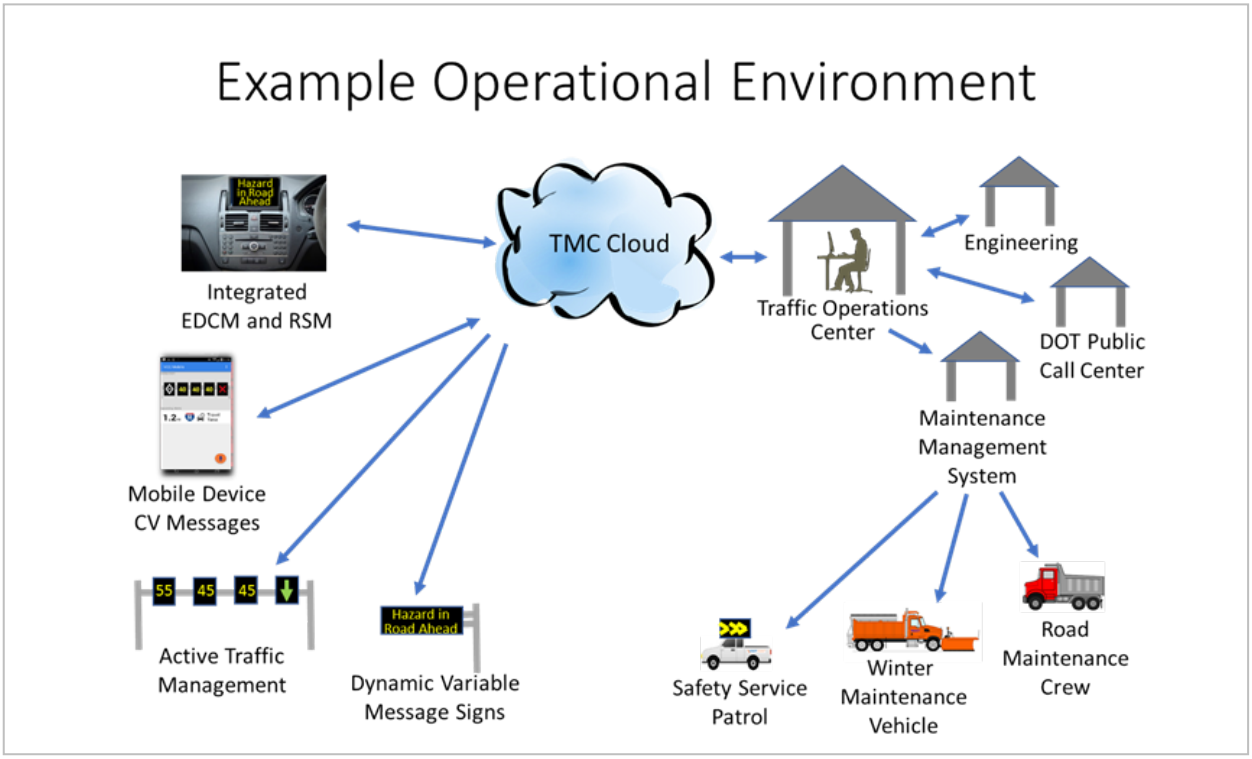

Figure 2: Illustration of Enabling Technologies, Systems, and Devices that are Leveraged to Support the EDCM Messaging Approach

3.3 Broad Vision for Nationwide EDCM Use

Local deployments of the infrastructure to exchange messages from the EDCM System with enabled IOO fleet vehicles and/or after-market applications in passenger or fleet vehicles may be the initial deployments of the EDCM System. However, broader, nationwide benefits will be

realized if production vehicles are EDCM-enabled and capable of communicating with any standards-compliant area that supports and utilizes messaging from the EDCM System to support TSMO activities.

Future market-driven aspects will define the business models for how EDCM Systems operate within TMC systems to communicate situation / event driven messages with vehicles. As illustrated in Figure 3, vehicles are likely to interface with multiple EDCM Systems, often on the same trip. EDCM Systems may encompass a metropolitan area, a regional area, or a broader rural area. Also, because EDCM Systems may be operated by IOOs in states, cities, counties, or regional areas, there may be areas where two adjacent EDCM Systems may overlap.

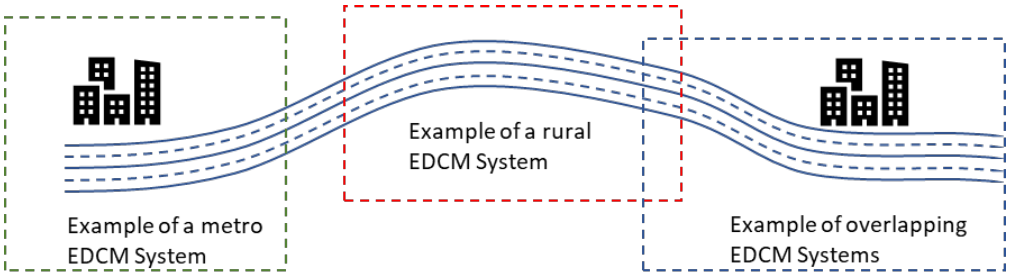

Figure 3: Illustration of Example EDCM System Coverage Areas

3.4 Details of the EDCM Environment

EDCM Systems established in areas where standards-compliant situation / event driven message exchanges can occur between the infrastructure and the vehicles in order to address the stakeholder needs identified by leveraging the EDCM environment. As EDCM environments and EDCM Systems are created and operated, there will be variations in the approaches. For example, some IOOs may utilize a metro area TMC with an EDCM System for message exchanges along major freeways in the metro area. Other IOOs may operate regional, statewide, or perhaps national EDCM Systems covering larger geographic areas. This section defines the elements of a typical EDCM environment. Section 4 will present operational concepts from the perspective of each EDCM System element.

The ***non-human elements*** expected to comprise the EDCM Environment include:

EDCM System A generic term for an Event Driven Configurable Messaging System consisting of flexible messaging, communication and information processing subsystems or components. It represents the functions performed by TMC or other systems that IOOs will deploy to perform their role in the EDCM environment. This would primarily consist of EDCM System components in the TMC that facilitate transmitting QMs, receive RMs from vehicles, processing data, creating information, advisories, or alerts and sending these to travelers and/or vehicles. Other supporting connected vehicle infrastructure, such as RSUs for short range, are expected to be in place for other applications and not directly part of the EDCM System but could be utilized by the system.

EDCM Communications Scheme	The wireless communications are used for the two-way data exchange between the TMC/TOC and the EDCM-enabled connected vehicles for this and other connected vehicle applications. Two-way wireless communication for data exchange is an integral part of the EDCM System for short- medium- and/or long-range communication.
EDCM-enabled Vehicles	A connected vehicle with appropriate application for two-way information exchange with the EDCM System and message processing software. These are typically privately-owned production vehicles.
EDCM-enabled Purpose-Built Vehicles	Purpose-built EDCM-enabled vehicles with expanded features such as more sensors to report additional data that are generally not available in production vehicles. These vehicles may include additional capabilities for processing of messages received (e.g., snowplow, truck mounted attenuator, incident response vehicle, delivery vehicle, etc.) specific to their role.
Non-EDCM-enabled Connected Vehicles	Connected vehicles either not enabled for the EDCM System or opted out from participating in two-way information exchange with the TMCs. However, these connected vehicles are equipped to send and receive messages with other vehicles and/or with the infrastructure for V2I applications.
Non-connected Vehicles	Vehicles that are not equipped with required on-board capabilities to be a connected vehicle and do not have ability to communicate with the EDCM System for two-way information exchange.
Infrastructure & Third-party Data Sources	Data sources that might support the creation of QMs communicated to vehicles. IOOs may combine data and information received through EDCM exchanges with other data to formulate actionable information or initiate EDCM QMs. Third-Party data sources may also receive data and information received from EDCM exchanges.
ATMS/ATIS	While not considered a core element of the EDCM System, IOOs will likely rely upon their existing ATMS, ATIS, and equipment to communicate event information to travelers and third-party navigation and information providers. These might include DMS, traveler information phone, web, and application, and active traffic management (ATM) systems.

Figure 4 illustrates the anticipated elements (human and automated) of a typical EDCM System.

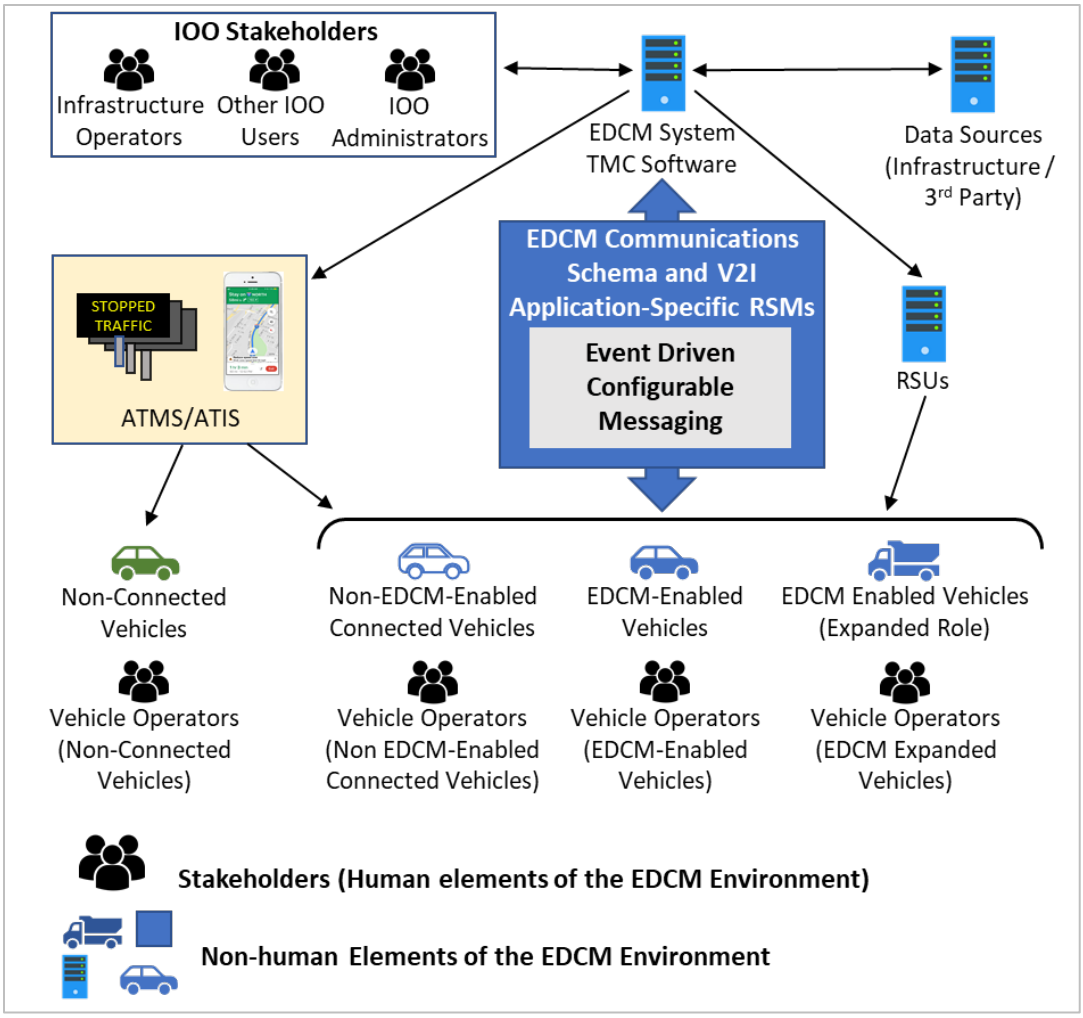

Figure 4: Illustration of the Elements of an EDCM Environment

3.5 EDCM Supported Use Cases

This section presents several exemplary use cases for the purpose of defining and exercising the EDCM System. These use cases were identified through outreach workshops throughout Virginia that were conducted as a part of this Project and are not necessarily 'all inclusive' of EDCM use cases. The use cases through outreach efforts were then further refined in order to convey the most common and impactful uses of the EDCM System. Each use case describes how the infrastructure system, connected vehicles, and communications will function to support the EDCM System. These use cases are used to support the creation of operational concepts that are presented in Section 5. The use cases presented below include:

- Traffic Condition
  - Queue Advisory / Queue Warning (QA/QW)
  - Work Zone Warning
  - Incident Detection
    - High Dynamic Maneuvers

        - Crash
- Roadway and Road Surface Management
    - Pothole or Other Roadway Surface Irregularities
    - Deficient Roadway Section
    - Engineering Analysis
- Weather Event

It is important to note that these are only example use cases. The EDCM System is explicitly designed to support a myriad of applications, including those which are not currently envisioned. Given the number of use cases and possibility of multiple, simultaneous active queries, the TMC is expected to assign priority with each QM. Moreover, the messaging framework permits new variables and algorithms to be shared between infrastructure and the vehicle, enabling the future of CADS transportation.

Traffic Condition Use Case

- The EDCM System uses configuration parameters to determine geographic areas or corridors, including freeway on-ramp areas, where queries will query regular vehicle data to provide continuous, low-frequency samples of the current traffic state on roadways of interest
- The EDCM System issues queries to vehicles within a geographic region
- EDCM-enabled vehicles receive the query and respond with the queried data, as specified by the EDCM System, e.g., travel speed
- The EDCM System aggregates received data with other sources to evaluate and determine current traffic flow conditions
- The EDCM System determines areas where queues may be forming to follow up with additional traffic flow condition queries.

Queue Advisory / Queue Warning Example of Traffic Flow Use Case

- The EDCM System uses configuration parameters to determine geographic areas or corridors where queries will request a vehicle to report when it has stopped, traveling below a certain speed or threshold, or some other measured indication of a queue
- The EDCM System issues queries to vehicles within a geographic region
- EDCM-enabled vehicles receive the query and respond with the requested data if conditions are met that indicate formation of queues, as specified by the EDCM System
- The EDCM System aggregates these data with other sources to evaluate and determine queue advisories and/or alerts
- The EDCM System notifies connected vehicles of queues via RSMs and the ATMS/ATIS notifies vehicle operators of non-connected vehicles

Work Zone Warning Use Case Example of Traffic Flow Use Case

- The EDCM System uses TMC data to identify work zone locations and information (e.g., position, configuration, activity, and status of work zones) in order to generate automated data queries for enabled vehicles approaching active work zone locations

- The EDCM System sends queries to vehicles approaching and within work zones for them to report data, e.g., their speed and position, through the work zone
- EDCM-enabled vehicles receive the query and respond periodically as requested by the EDCM QM as they progress through the work zone, reporting the data requested by the EDCM System each time, e.g., speed and position, as appropriate. The timing of responses is either specified by the query or driven by the trigger conditions (e.g., queries that request a response when hard braking occurs would respond only if the trigger (hard braking) occurs).
- The EDCM System combines responses to work zone related queries from EDCM vehicles with other available data and updates work zone-related queries sent to EDCM-enabled vehicles to gather more details of actions around the work zone
- The EDCM System shares data received from RMs with the TMC or other systems
- The TMC (or other systems) combines the EDCM received data with other data collected on the system and shares actionable end information with travelers through ATMS/ATIS solutions. The TMC may alert work zone managers in order to make operational changes to the work zone, if needed. The TMC also shares information with connected vehicles through the generation and broadcast of RSMs.

Incident Detection Example of Traffic Flow Use Case for High-dynamic Maneuvers and Crashes

- The EDCM System uses configuration parameters to specify vehicle actions, variables, and threshold values to be queried from vehicles to assist in detecting various types of incidents, e.g., high-dynamic maneuvers or crashes
- The EDCM System issues queries to vehicles within a defined area such as geographic region, highway network (e.g., all state highways, all interstates, specified corridors, or a roadway network within a geographic region), or corridors
- EDCM-enabled vehicles receive the query and respond with the requested data if conditions are met that are indications of incidents. This data is expected to vary for different incident use cases. For example, high-dynamic maneuvers may be identified with data regarding hard braking by the vehicle, vehicle swerving, anti-lock braking system (ABS) activation, traction control system (TCS) activation
- The EDCM System receives query responses and takes appropriate actions based on the type of incident information that has been reported
    - For reported *high-dynamic maneuvers*, EDCM-enabled vehicles will not specifically be able to report the cause of these indicators (e.g., hard braking could be an isolated operator action and not caused by an incident). Therefore, the EDCM System may issue new queries to request additional, more detailed data from other vehicles traveling within a small area surrounding the point of the initial report to obtain more indicators of an incident from other vehicles. Additionally, an operator may dispatch responses and issue warning messages via the ATMS/ATIS.

- For a reported *crash*, the EDCM System interacts with the ATIS and ATMS to notify first responders of incidents and send messages to other road users, e.g., EDCM-enabled vehicles or non-equipped vehicles.

Roadway and Road Surface Management Use Case

- The EDCM System configuration specifies applicable variables and thresholds to be used to record:
  - *Potholes or other roadway surface irregularities* where maintenance is needed
  - *Deficient roadway section* where changes to road geometry or additional signage could improve safety on a specific segment
  - *Engineering analysis* data as historic information for evaluating general roadway design that might impact safety and mobility
- The EDCM System issues queries to vehicles within a defined area, such as geographic region, highway network (e.g., all state highways, all interstates, specified corridors, or a roadway network within a geographic region), or corridors
- EDCM-enabled vehicles receive the query and respond with the requested data if conditions are met that match the query
  - *Potholes or other roadway surface irregularities*, i.e., vertical offsets, may be identified by data such as vertical, lateral, or longitudinal acceleration, turn-signal activation, or pitch or yaw rotation
  - *Deficient roadway sections* may be identified by data regarding hard braking by the vehicle or ABS activation
  - *Engineering analysis* data may include speed, TCS activation, ABS activation, ESC activation, vertical, lateral or longitudinal acceleration, turn-signal activation, roll pitch or yaw rotation
- The EDCM System receives query responses and aggregates them with additional input and responses from other vehicles, determining whether agency staff should investigate the need for possible repairs, maintenance needs, roadway geometry improvements, or additional signage, while also populating an archive of historic information that is used to support agency staff decisions regarding roadway design.

Weather Event Use Case

- The EDCM System configuration specifies applicable variables and thresholds to be used to detect possible safety or mobility weather events, e.g., ice on road, water on the roadway surface
- The EDCM System issues queries to vehicles within a defined area (e.g., geographic region of interest), highway network (e.g., all state highways, all interstates, specified corridors, or a roadway network within a geographic region), or corridors
- EDCM-enabled vehicles receive the query and respond with the requested data if conditions are met that are indications of weather, as requested by the EDCM System, e.g., TCS activation, ABS activation

- The EDCM System receives query responses and aggregates them with additional input and responses from other vehicles, as well as other data sources to support agency staff, ATIS, and ATMS systems determination of when to treat road conditions and when to inform vehicle operators about the conditions.

4 Conditions

The sections that follow provide a basic description of the underlying assumptions about the roadway environment and vehicle parameters that apply to all concepts and use cases described in this document. Note that the specific inclusion or exclusion of any roadway type, vehicle class or description of any parameters for this document does not preclude changes being made at some future point to modify the proposed system.

4.1 Anticipated Roadway Conditions for the Proposed System

4.1.1 Conditions for the Initial EDCM System Concept

When EDCM capabilities are first introduced, the System will be supported and available on a limited number of roadways. Specifically, this may include select segments or corridors of freeways, tolled bridges and highways, and managed lanes that are identified by IOOs as locations that could most benefit from connected vehicle applications and are equipped with RSUs that could also support EDCM. Additionally, the number of CADS that possess required EDCM capabilities is initially expected to be low. This limited, initial EDCM System will allow the IOOs to incrementally test and deploy required infrastructure, make improvements, and expand upon EDCM applications and related systems in a sustainable manner.

4.1.2 Conditions for Eventual Fully Developed EDCM System

Eventually, EDCM capabilities will be expanded nationally and could encompass the entire limited-access highway network, including the Interstate Highway System and other freeways and tolled highways. Additionally, other highways or arterials may be identified by state and local IOOs for inclusion into the EDCM System.

4.2 Anticipated Vehicle Types and Conditions

4.2.1 Vehicle Types for Initial EDCM System Concept

Initially, it is expected that OEMs will test the EDCM System concept using only a limited number of vehicles, potentially with aftermarket OBUs. As the EDCM System concept matures and is made publicly available, the required connected vehicle capabilities to support the EDCM System will likely only be available on a limited number of vehicles makes and models. Additionally, vehicle owners may be required to opt-in to support the provision of vehicle status data queried by TMC as part of the EDCM System.

4.2.2 Vehicle Types for the Eventual Fully Developed EDCM System

Eventually, it is anticipated that connected vehicle capabilities will be available in nearly all vehicle makes and models, greatly increasing the percentage of the nationwide vehicle fleet that is capable of supporting EDCM and opted in by the vehicle owners to support EDCM. In this future state, the EDCM System's ability to control message traffic may be particularly important to ensure scaling is feasible to strike a balance between data transmission volume and operational cost of connected vehicle applications.

4.3 Anticipated Use of Configurable Messages

An overview of the configurable messages (e.g., QMs, RMs) that are expected to be included in EDCM data exchanges is provided in Section 1.2 of this document. A data dictionary will be used to define approved data elements that may be used in the QMs and RMs. The terms in the data dictionary will be complete and unambiguous such that there is no interpretation required. Note that not all elements may be supported by all vehicles nor would any vehicle be required to respond with all or any queried data elements.

It is envisioned that the data dictionary will periodically require updates to add new elements, creating situations where a vehicle may not have the latest data dictionary elements used by an EDCM System. The configurable messaging approach in EDCM will ensure backward compatibility, enabling a vehicle supported by an outdated EDCM data dictionary to still receive QMs and process those messages it recognizes and ignore those it does not.

Over time, as vehicles update and the data dictionary stabilizes, it is intended that the vast majority of vehicles will operate with data dictionaries that are compatible with the EDCM System. Still, additional data elements may be added at any time as the framework is explicitly designed to permit compatibility with future applications through its inherent flexible design. Over the air updates of vehicles may also allow vehicles to make use of the full EDCM capabilities as it evolves post-deployment.

5 Operational Concepts

Operational concepts are provided below to represent distinct perspectives of each element of the EDCM System reflecting the conditions presented in Section 4.

5.1 EDCM Enabled Vehicles' Perspective

5.1.1 EDCM Activation

- EDCM will activate after a vehicle owner / operator has 'opted-in' to participate in EDCM-based information exchange, which may be by default or supported via a user interface, depending on the make, model, and class of vehicle, as well as whether it is a private or fleet vehicle which will likely be a simple process, e.g., the vehicle operator and/or owner checks a box on a user interface to agree to 'opt-in.'
- After EDCM is activated, EDCM will operate in the background, without human driver or passenger input or intervention required, waiting to receive and respond to EDCM queries.

5.1.2 EDCM Use of V2V Communications

- EDCM will cause no change in how the vehicle is (or is not) receiving and utilizing V2V messaging. Receiving and processing BSMs from other vehicles will continue as it does without EDCM.
- EDCM will cause no change in how the vehicle is (or is not) transmitting BSMs.

5.1.3 EDCM Use of V2I Infrastructure Communications

- The messaging structure for flexible query and response in the EDCM System is defined using eXtensible Markup Language (XML)[2], a widely adapted industry standard. Associated schema are defined for the messaging language expressing constraints, structure and elements necessary for formulating query and response messages. The XML-based QM and RM makes the EDCM System highly portable, adaptable and extensible for supporting future needs.
- EDCM-enabled vehicles will receive QMs that are communicated by the EDCM System.
- EDCM-enabled vehicles will process the received QM and reply to the EDCM System with a response message (RM) when the conditions specified within the QM are satisfied.
    - Replies to QMs will always be optional, based on available data and computing resources. On-board safety applications (e.g., a collision warning system) would have priority and may provide delayed or no reply to a QM.
    - Replies to QMs may be configured to start transmitting messages when the QM is received or as soon as the conditions for transmission are set (e.g., triggering of the Incident Detection Weather Event Use Case).
    - Replies to some QMs may be delayed and only occur when the vehicle experiences a situation that matches the QM request. One example is the QA/QW Use Case, where the vehicle receives a QM and replies with data as the vehicle experiences

[2] For more information, see: https://en.wikipedia.org/wiki/XML.

effects of queues on traffic. Another example is Incident Detection Dynamic Maneuver Use Case where the EDCM System has issued a QM to vehicles for a region and the vehicle responds when vehicle actions suggest an incident (e.g., hard braking, swerve, or ABS activation).
    - Each QM is assigned a unique event message identification number and processing priority. When multiple QMs are received and conditions for each are met, replies will be made according to the priority that is assigned by the IOO within each QM based on the order received.
- In some locations, EDCM-enabled vehicles will receive QMs from multiple IOOs, replying to each individually with a RM specific to the queried messages from each IOO. A unique event ID is utilized in QM to differentiate between QM and the RM includes the received event ID for TMCs to correlate the responses from EDCM-enabled vehicles.
- Connected Vehicles may receive additional data, message or information from the TMC (e.g., in the form of RSMs). These messages may be processed by on-board applications to support the vehicle operator (human or machine).
- Configurable messages sent to and from the vehicle (in the form of QM and RM) will be based on an established messaging language schema and data dictionary of terms and definitions.
    - The QMs and RMs can be determined in real-time, while using established data dictionary terms.
    - A vehicle may receive a QM that contains data elements that the vehicle does not recognize (e.g., either because the vehicle system has not been updated or because there are local data dictionary elements not supported by the vehicle). In these situations, because the EDCM functionality will be backward compatible, the vehicle would generate a RM with elements it recognizes and can support based on current on-board schema/data dictionary and ignore portions of the QM it does not recognize.
    - An EDCM-enabled vehicle that receives a QM may recognize all data elements in the QM and be capable of generating responses to some or all the elements requested in the QM.

5.1.4 Processing EDCM Queries and Formulating Responses

- EDCM-enabled vehicles will process the QMs received and formulate RMs as responses when appropriate.
- EDCM-enabled vehicles will compare the contents of the QM to the data dictionary elements that the vehicle understands. The vehicle may process and understand all the elements queried, a portion of the elements, or none of the elements.
- For elements of the QM that the vehicle does not recognize, no associated response will be formulated.
- For elements of the QM that the vehicle recognizes, the vehicle may or may not generate a response, depending upon the element queried.

  - If a vehicle recognizes the element queried and has the sensing capability to collect the queried data, it will determine if a response is possible and formulate a response when appropriate given the conditions of the QM are realized.
  - Formulation of the responses may involve sending raw collected data or some data processing to create a RM response message.
- The QMs will be based on a data dictionary, known by both the vehicle and the infrastructure system, with enough detail to avoid ambiguities. For example, 'vehicle speed' would be well defined to indicate if this is either: the most recent speed value, an average speed over the last XX seconds, or some other measure. There will be no ambiguity in what the data dictionary elements are or what data they include.
- QMs may include geofence boundaries, requesting only replies from vehicles within the boundary.
  - Geofence boundaries may include latitude/longitude coordinates of a polygon. In these situations, applications will only reply if located within the boundaries of the polygon. An example of a geofence boundary would be the Work Zone Warning Use Case, where the query region may include the area within the work zone and immediately upstream and downstream of the work zone.
  - Vehicles in positions outside the geofence boundaries will not respond to geofence queries. There will not be a response that indicates "I am outside the geofence boundary."
- QMs may include queries for real-time acquired data, such as ambient temperature or vehicle speed. In these situations, the EDCM-enabled vehicle will assemble the data into the reply message.
- QMs may include queries for summary or composite data, such as speed values for the preceding 10 seconds. In these situations, the EDCM-enabled vehicle will perform calculations with available data to assemble the queried message to the extent possible.
- QMs may include queries for vehicle maneuvers, such as indications of hard braking or steering control. In these situations, the EDCM-enabled vehicle will assemble the data into the reply message, as it is or becomes available within the specified geofenced area. No response from the EDCM-enabled vehicle indicates required condition(s) are not met by the vehicle which could be either the geofenced area or queried triggering condition in the query. Rationale for this strategy is to reduce communication overhead by the vehicles that are not meeting the condition.
- QMs may include queries for conditional data, such as notification about a queue given the EDCM-enabled vehicle is traveling below a certain speed or stopped. In these situations, the EDCM-enabled vehicle will assemble the data into the RM, as it is or becomes available within the specified geofenced area. If the conditions are not met, the EDCM-enabled vehicle will respond with a heartbeat message to notify the EDCM System that the query was received.
- EDCM-enabled vehicles may not be able to respond to all QMs, e.g., if an EDCM-enabled vehicle receives a QM and does not have the queried data or has limited processing capability to formulate the queried response. When multiple QMs are received at once, the

EDCM-enabled vehicle will respond to QMs according to the priority associated with each received QM in the order that they are received.

5.1.5 Security of Data and Information

- EDCM will follow the same processes, guidelines, and systems established for overarching security and Personally Identifiable Information (PII) that are developed and implemented nationally for other connected vehicle applications and communications.

5.1.6 EDCM Deactivation

- EDCM-enabled vehicles will have a provision to stop participating in EDCM information exchange with the TMC, as desired.
- The TMC will have a mechanism to deactivate the EDCM System or specific QMs, as desired.

5.1.7 EDCM Expanded Vehicles

- Some EDCM-enabled vehicles may have the capability to perform additional sensing and monitoring, such as environmental sensors, to provide additional data.
- EDCM-enabled vehicles with expanded capabilities may respond to queries that non-expanded vehicles cannot respond to, i.e., when queries are for specific data elements not measured by all vehicles.

5.2 Non-EDCM-enabled Vehicles' Perspective

5.2.1 Vehicles that are Not Connected Vehicles

- Vehicles that are not equipped to reply to EDCM queries will function in areas with an EDCM System as they do in other areas (i.e., no QMs will be received, processed, or responded to).

5.2.2 Non-EDCM-enabled Vehicles that are Connected Vehicles

- Vehicles that are not enabled to exchange EDCM information or have decided to opt out but are equipped to receive other V2I application messages will receive messages from the infrastructure that contain information that may in part be based on EDCM information from other vehicles.
- Non-EDCM-enabled vehicles that exchange other V2V messages with other vehicles or V2I messages with infrastructure will not be impacted by the operations of EDCM.

5.3 EDCM System Perspective

5.3.1 Formation of Queries

- The TMC would likely have to update existing systems to support the EDCM System and automatically generate appropriate queries and exchange information with connected vehicles.

- To the extent possible, the EDCM queries can be automated following initial configuration activities to avoid adding manual activities to the responsibility of the operators or the administrators.
- ***Manually Activated Queries.*** While a goal of EDCM is to reduce operator actions, the EDCM System may enable infrastructure operators to manually create on-demand messaging queries for vehicles. These queries may be in response to observed conditions or manual reports where IOO operators want to verify a condition or situation. Use cases that are likely to benefit from on-demand queries include:
    - *Weather Event:* Where the infrastructure operators may manually elect to poll vehicles because conditions are such that weather may be impacting travel and they wish to receive feedback from vehicles, e.g., precipitation falling and temperatures just above freezing. Similarly, operators or administrators may define triggers that automatically poll vehicles when ambient conditions meet the triggers (e.g., temperatures below 34 degrees).
    - *Incident Detection:* High-dynamic Maneuver: Where a maneuver has been reported by a vehicle, e.g., hard braking. The infrastructure may automatically create more specific queries to the specific geographic region surrounding the maneuver report.
- ***Automatically Triggered Queries.*** The EDCM System will enable infrastructure operators to send automated queries to EDCM-enabled vehicles only when conditions meet pre-defined triggers. These queries may be configured to occur when ambient weather conditions are met or during time of day, day of week periods, or when traffic conditions meet the predefined trigger thresholds. Use cases that are likely to benefit from on-demand queries include Weather Event and Incident Detection/High-dynamic Maneuver.
    - *Weather Event:* Where the infrastructure operators may create an automated query for friction data from vehicles during periods when temperatures are between 26 degrees and 34 degrees. In this example, IOO Operators would not need to manually activate these queries, rather they would initiate when the trigger threshold is met.
    - *Incident Detection:* High-dynamic Maneuver: Where a maneuver has been reported by a vehicle, e.g., hard braking, and the infrastructure may automatically create more specific QMs to the specific geographic region surrounding the maneuver report.
- ***Continuous Queries.*** The EDCM System will enable IOO operators to create continuous, automated queries that are continuously transmitted to EDCM-enabled vehicles for a response only when specified conditions are met. When responses are received, additional, follow-up queries to EDCM-enabled vehicles may be automatically initiated by the EDCM Systems or manually by IOO operators to monitor conditions. Use cases that are likely to benefit from continuous queries include:
    - *Work Zone Warning Use Cases:* Where the infrastructure operators configure the EDCM System to transmit QMs for the duration of the work zone, requesting input from vehicles.

  - *Incident Detection and Weather Event Use Cases:* Where QMs may be continuously used to request vehicles to report conditions when they are encountered.
  - *Queue Advisory / Queue Warning Use Case:* For areas with recurring congestion or frequent vehicle queuing so vehicles may respond when congested conditions or queues occur.
- ***EDCM Regional Queries.*** The EDCM System will enable IOO operators to send QMs to vehicles within the entire jurisdiction that an IOO is operating EDCM. Use cases that are likely to benefit from regional queries include:
  - *Incident Detection and Weather Event Use Cases:* Where QMs may be used throughout the region to request vehicles to report conditions when they are encountered.
  - *Roadway and Road Surface Management Use Case:* Where the compilation of data could be useful to maintenance staff and/or design engineers and planners within the IOO.
- ***Geo-fenced Queries.*** The EDCM System will enable IOO operators to send QMs to vehicles within specific areas where the IOO is particularly interested in understanding conditions, e.g., locations where existing DMS are in place to warn upstream traffic of queues. Use cases that are likely to benefit from geo-fenced queries include:
  - *Queue advisory / Queue Warning Use Case:* Where QMs may be targeted to areas prone to the formation of queues (e.g., interstates), or where roadway geometrics increases the risks of vehicle operators not visibly observing queues (and therefore more need for generating automated warnings), or areas where upstream DMS could alert non-connected vehicles and RSMs could alert connected vehicles.
  - *Work Zone Warning:* Where the infrastructure operators configure the EDCM System to transmit queries for the areas upstream, within, and immediately downstream of the work zone, requesting input from vehicles.
  - *Roadway and Road Surface Management Use Case – Engineering Analysis:* Where the engineers and planners have a specific area that they are interested in gathering a historic record.
- Table 2 below partitions the use case examples discussed by query frequency and location type.

Table 2: EDCM Use Case Examples by Query Frequency and Location Type

		Query Frequency		
		Automatically Triggered	Continuous Queries	Manually Activated
Query	Region-wide	• Weather Event Use Case • Incident Detection – Dynamic Maneuver Use Case	• Incident Detection Use Case	

		Query Frequency		
		Automatically Triggered	Continuous Queries	Manually Activated
		• Roadway and Road Surface Management Use Case		
	Geo-fenced to Specific Locations	• Roadway and Road Surface Management Use Case – Engineering Analysis	• Incident Detection Use Case • Work zone Warning Use Case • Queue Advisory / Queue Warning Use Case1 • Weather Event Use Case	• Incident Detection Use Case

5.3.2 Transmitting Queries

- Each EDCM System will transmit its own QMs. This may include state and local IOOs, and specialty authorities such as bridge, tunnel, toll turnpike authorities, etc.
- EDCM QMs can be transmitted to enabled vehicles using wireless communications that support short-, medium- or long-range communications, i.e., using roadside units, the cloud, or other communications protocols to exchange messages.

5.3.3 Receipt and Processing of Responses

- Each EDCM System will operate its own system to receive RMs from vehicles.
- The EDCM System will be able to receive and process RMs received from wireless communications using whatever mode of communication is available or preferred.
- The processing and use of query responses will be defined and operated locally by each EDCM System. Processing may be tied to centers such as TMCs as well as to automated functions of ATMS software, an ATIS, or other local systems.
    - Processing and use of query responses will most likely depend upon the use cases implemented by each TMC operating EDCM System.

5.3.4 Transmitting Direct Communication of Messages to EDCM-enabled Vehicles

- The EDCM System may transmit QMs to be potentially received by any EDCM-enabled vehicle within the vicinity (i.e., there is not a confirmed communication exchange).
- Depending on what wireless communications are available or preferred, the TMC may have direct communication with the EDCM-enabled vehicle.
- The EDCM System is able to query responses from a random sample of all the vehicles that receive the QM, as opposed to every single vehicle responding to the QM. This is a useful feature in an application such as Engineering Analysis where the TMC needs representative data from a population of vehicles. However, if every vehicle responded to the QM it would lead to a data overload at the TMC.

5.3.5 Data Distribution

- The distribution and sharing of data from RMs received by the EDCM System will be defined and operated locally by each EDCM System operating in an area.
- In the event that a single TMC supports an EDCM System for multiple IOOs, the RMs received by the EDCM System will be distributed and shared with respective IOOs, as appropriate.

5.3.6 Security of Data and Information

- The communications between the vehicle and the EDCM Systems will be anonymous in accordance with an industry accepted security credentialing approach. Security approaches may require a temporary identifier (ID) or other mechanism to adhere to credentialing standards, but personal information will be protected to the extent possible.

5.4 EDCM Communications Schema Perspective

- EDCM Communications Schema will transmit EDCM QMs from the EDCM System to EDCM-enabled vehicles. This may be accomplished using different communications methods, such as those described below.
    - EDCM Communications Schema may transmit QMs using backhaul communications from the TMC EDCM System to the RSUs. Then short-range wireless communication from RSU to vehicles for low-latency communications would be used for transmitting QMs to the local vehicles.
    - EDCM Communications Schema may communicate QMs directly from the EDCM System at the TMC to EDCM-enabled vehicles via wide-area medium- or long-range wireless communications.
- EDCM Communications Schema will transmit EDCM RMs from the EDCM-enabled vehicles to the EDCM System at the TMC. This may be accomplished using the same communications method that was used for sending the EDCM QMs.
    - The EDCM System at the roadside, if present, may receive EDCM RMs using EDCM Communications Schema and conduct data processing locally before transmitting processed summary data to the EDCM System at the TMC using backhaul communications infrastructure.

5.5 Vehicle Operators' Perspectives

5.5.1 Operators of EDCM-enabled Vehicles

- Opt-in to EDCM may be by default or be supported via a user interface, depending on the make, model, and class of vehicle, as well as whether or not it is a private or fleet vehicle.
- After EDCM is activated, EDCM will operate in the background, with no vehicle operator input or intervention required.

- Some vehicle operators may have EDCM-enabled vehicles that can perform expanded roles given additional sensing and monitoring capabilities on their vehicle, such as environmental sensors, that can provide additional data.
    - Operators of EDCM-enabled vehicles with expanded capabilities will not directly receive any information that is different than any other EDCM-enabled vehicle. However, the expanded EDCM information may be used by the EDCM System to send enhanced and improved messaging to the vehicle for other purposes (e.g., material application for winter weather conditions).
    - Operators of EDCM-enabled vehicles will benefit from data received by OBUs via RSMs. In locations where EDCM is operational, information in the RSM will be timelier and benefit from increased details from EDCM-enabled vehicles.

5.5.2 Operators of non-EDCM-enabled Connected Vehicles

- Operators of non EDCM-enabled connected vehicles have either elected to 'opt-out' of participation in EDCM information exchange or do not have EDCM capabilities on the vehicle.
- Operators of non-EDCM-enabled connected vehicles will benefit from data received by OBUs via RSMs. In locations where EDCM is operational, information in the RSM will be timelier and benefit from increased details provided by surrounding EDCM-enabled vehicles.

5.5.3 Operators of Non-connected Vehicles

- Operators in a vehicle that is not a connected vehicle will operate their vehicle as they do now.
- Operators in a non-connected vehicle may benefit from additional information that is generated by EDCM-enabled vehicles, processed, and disseminated on agency ATMS/ATIS, e.g., DMS, 511 phone service, traveler information websites, mobile apps, or via third-party information providers.

5.6 IOO Stakeholders' Perspective

5.6.1 IOO Operators

- IOO operators will set and update criteria for automatically identifying locations where EDCM queries would be beneficial for obtaining additional information on traffic and/or road conditions.
    - These criteria may rely on planned and/or archived information that indicates locations where adverse traffic conditions may occur based on planned work zone activities, forecast adverse weather, areas with recurring queues, or other conditions.
    - EDCM data queries that are created based on set criteria will be automatically sent to vehicles for a specified location at the scheduled time, if so defined.

    - IOO operators will be able to review automatically generated EDCM QMs through data visualization systems but will not be required to manually review QMs.
    - IOO operators will have the option to remove automatically generated EDCM QMs before they are sent.
- IOO operators will access IOO-generated data sources in order to manually identify locations for better situational awareness of the transportation system using EDCM QMs, including locations of incidents, work zones, adverse weather, queues, or other events where more information may be desired.
    - EDCM QMs to vehicles will include geographic boundaries defined for the queries. IOO Operators will likely have a user-friendly mechanism to define the region of interest for query locations. This may include a selection of routes and starting or ending points, each of which may be converted into the appropriate geographic region for EDCM-enabled vehicles to respond to the queries.
- IOO operators may manually engage the EDCM System to make specific data queries to vehicles in given locations at specified times and may also review and/or approve automated EDCM queries.
    - The EDCM QMs may be scheduled for a future time and include a broader, follow-up data query from additional vehicles for more data elements if an initial response indicating adverse road or travel conditions is received.
- IOO operators may receive notifications when incidents, queues, or other unplanned events are identified from EDCM RMs.
- IOO operators may view EDCM RM information received from vehicles to create and issue a follow-up EDCM QM to vehicles. This may include aggregated EDCM RM data or a processed summary of the EDCM RM information to help IOO operators understand the received information.
- IOO operators may view EDCM RM information received from vehicles to take action, (e.g., generate and issue messages for transmission to connected vehicles or on agency ATMS/ATIS; request assistance by IOO incident response teams, law enforcement, or emergency services; or other actions).
    - IOO operators may also rely on automated processes to take operational actions for travelers and notify internal and external stakeholders, as needed.

5.6.2 IOO Administrators

- IOO administrators will set and update criteria for automatically identifying locations where EDCM queries would be beneficial for obtaining additional information on traffic and/or road conditions.
    - These criteria may rely on planned and/or archived information that indicates locations where adverse traffic conditions may occur based on planned work zone activities, forecast adverse weather, areas with recurring queues, or other conditions.
    - EDCM QMs that are created based on set criteria will be automatically sent to vehicles for a specified location or area at the scheduled time.

- IOO administrators will be responsible for establishing business processes and configure the data elements for various types of EDCM QMs.
- IOO administrators will be responsible for establishing business processes for processing the RMs that are received from vehicles.
- IOO administrators will manage the compatibility of the EDCM System with other IOO systems, especially during hardware or software updates or upgrades.
- IOO administrators will manage permissions for who may access EDCM data and infrastructure, including IOO operators who may manually create EDCM QMs or establish criteria to generate automatic EDCM QMs and other IOO who may access EDCM data.

5.6.3 Other IOO Users

- Other IOO users may submit requests for EDCM data for specific locations and/or specific times to IOO administrators or IOO operators to support planning, design, or maintenance activities.
- Other IOO users may benefit from EDCM data that is automatically ingested into systems to be processed and visualized alongside other data sources (e.g., EDCM data may be automatically ingested into a Maintenance Decision Support System (MDSS) for improved road treatment recommendations).
- Other IOO users like planners or designers may manually access generated EDCM data for non-real time purposes to improve the safety and mobility of the network, e.g., by identifying locations with possible vertical offsets in the road surface that could indicate potholes or other roadway surface irregularities.
- Other IOO users like maintenance or operations staff may manually access generated EDCM data for real-time management, e.g., using a Maintenance Management System (MMS) or MDSS.

5.7 Data Sources Perspectives

5.7.1 Providing Data for IOO Users for EDCM Queries

- When creating EDCM QMs, data sources including IOO systems, third-party probe data, and citizen reports may provide information to IOO operators about the transportation system, including locations of incidents, work zones, adverse weather, queues, or other events where more information may be desired by using EDCM.

5.7.2 Ingesting EDCM Data

- Data sources, which include public and private sources of traveler information, will continue to ingest data from a variety of sources, as in the current state, including stationary and mobile sensors, citizen reports, IOO users, and other IOO systems. The EDCM System represents a new data source that may now be ingested.
- Data sources will continue to process data received from a variety of sources for it to be presented in an accessible and user-friendly format. Datasets from EDCM and other

connected vehicle data sources will be large and will likely require additional data processing capabilities than the current state.

5.8 IOO Operated ATIS/ATMS Perspectives

5.8.1 Ingesting EDCM Data

- IOO operated ATIS/ATMS will continue to ingest data from a variety of sources, as in the current state, including stationary and mobile sensors, citizen reports, IOO users, and other IOO systems. The EDCM System is a new data source that is now ingested.
- IOO operated ATIS/ATMS will continue to process data received from a variety of sources for it to be presented in an accessible and user-friendly format. Datasets from EDCM and other connected vehicle data sources will be large and will likely require additional data processing capabilities than the current state.

5.8.2 Disseminating Data

- ATIS/ATMS, which includes processed EDCM data, may be directly accessed by travelers via 511 phone service, traveler information websites, mobile apps, navigation systems, or other third-party providers. Events displayed on the ATIS/ATMS user interface may include incidents, work zones, slowed or stopped traffic, adverse weather conditions, or other information that was created, updated, or informed as a result of EDCM data.
- ATIS/ATMS, which include processed EDCM data, will also send messages to connected vehicles to improve safety and mobility about downstream impacts to traffic or the roadway surface caused by incidents, work zones, adverse weather, queues, or other events. Connected vehicles will receive the application specific RSMs regardless of whether the connected vehicle is EDCM-enabled or not.
- ATIS/ATMS, which include processed EDCM data, will be accessed by IOO operators for posting messages on DMS and via other traditional roadside technologies, as appropriate.
- ATIS/ATMS, which include processed EDCM data as well as enhanced EDCM data, will be accessed and used by IOO systems to automatically initiate operational actions or make recommendations, e.g., post travel times or specific messages on DMS, or provide treatment recommendations on maintenance decision support systems.

6 Glossary

AMCD	Advanced Messaging Concept Development – Project that preceded EDCM and evaluated "the ability of connected vehicles to generate, and infrastructure to collect, Basic Safety Message (BSM), Probe Data Message (PDM), and Basic Mobility Message (BMM) alternatives using both cellular and DSRC, employing basic message control strategies in real-world driving conditions for non-safety-critical applications."
BSM	Basic Safety Message – A standard SAE-defined message communicated from equipped vehicles containing data elements that include, for example, vehicle location and acceleration.
EDCM System	Event Driven Configurable Messaging System – A flexible messaging approach for two-way data exchange between the transportation management center (TMC) and enabled connected vehicles, a wireless communication subsystem for data exchange and information processing subsystem for generating actionable information.
EDCM Environment	Event Driven Configurable Messaging Environment – Extends beyond the EDCM System to encompass other existing connected vehicle technologies, systems, communications, and devices that are supporting elements required by EDCM but expected to be deployed independently and not specifically to support an EDCM System.
IOO	Infrastructure Owner Operator – The public or private agency that owns, operates, and/or maintains the roadway and is responsible for providing infrastructure-related data via road safety messages (RSMs).
QM	Query Message – An EDCM message sent from the transportation management center (TMC) to connected vehicles using available and preferred short-, medium-, or long-range communications with a messaging language to request feedback on current conditions either on periodic bases or instance based for a selected geofenced area.
RM	Response Message – Optional message that is sent by vehicles to the transportation management center (TMC) using available and preferred short-, medium-, or long-range wireless communications as a response to a received Query Message (QM) with requested vehicle status data, as available.
RSM	Road Safety Message – A work-in-progress standard message development at SAE to communicate to connected vehicles from the IOO containing data elements such as target speed and target time gap.

RSU	Roadside Unit – A unit that provides wireless communications from roadside infrastructure to vehicle On Board Units (OBUs).
TMC	Transportation Management Center – A physical center or virtual capability for IOO staff to access agency systems to manage the transportation network. Sometimes referred to as a transportation operations center (TOC).
V2I Communications	Communications capability enabling vehicles and infrastructure to exchange messages, such as the Road Safety Message (RSM), between the infrastructure owner operator (IOO) and vehicles using short-, medium-, or long-range communications such as cellular or dedicated short-range communications (DSRC), for example.
V2V Communications	Communications capability enabling vehicles to exchange messages, such as the Basic Safety Message (BSM), between vehicles.