CAMP LLC

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

Vehicle-to-Infrastructure Program

Event-Driven Configurable Messaging (EDCM)

Queue Advisory & Queue Warning (QA/QW) System and In-Vehicle Application Requirements

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Federal Highway Administration (FHWA)

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In Response to Cooperative Agreement Number
DTFH6114H00002

Executive Summary

This document develops the requirements for a Queue Advisory & Queue Warning (QA/QW) system. The requirements are developed in cooperation with the Connected Vehicle Pooled Fund Study in support of Vehicle-to-Infrastructure (V2I) Queue Advisory / Warning Concept and Design Project. The QA/QW system detects queues and provides relevant information about the queue to the connected vehicles to determine an appropriate action. The QA/QW system operates under an Event Driven Configurable Messaging (EDCM) framework. EDCM leverages existing connected vehicle infrastructure and communications to identify events and road conditions that potentially impede the safety and mobility of the traveling public. A congested road segment or 'queue' of vehicles is one example of such an event. The EDCM Project was conducted by the Crash Avoidance Metrics Partners LLC (CAMP) Vehicle-to-Infrastructure 2 (V2I-2) Consortium, consisting of Ford Motor Company, General Motors LLC, Hyundai Motor Group and Toyota, in cooperation with the Virginia Tech Transportation Institute. The Project was sponsored by the Federal Highway Administration (FHWA) through Cooperative Agreement DTFH6114H00002.

The EDCM system operates within the larger connected vehicle (CV) environment, which includes supporting communication infrastructure, security protocols and privacy management techniques required for EDCM to function. It enables a Transportation Management Center (TMC) to request information from CVs equipped with EDCM capabilities in specified areas regarding current conditions at varying rates and time of day. EDCM-equipped CVs then provide vehicle dynamics and status data in response when, where, and as often as requested by the TMC using a flexible messaging schema.

The Query Message (QM) sent by the TMC is based on a well-defined data dictionary, known to both the connected vehicle and the infrastructure system. In this initial design, 23 different vehicle measurements / parameters identified in the project can be requested in a query. The TMC aggregates Response Messages (RM) received from EDCM equipped CVs and combines the information with data from external roadside sensors and third-party data. In the QA/QW application, if the TMC detects traffic congestion / queue formation, it returns actionable information to all CVs using a Road Safety Message (RSM). This information may also be distributed to non-connected vehicles using Dynamic Message Signs or other conventional techniques. The EDCM flexible messaging schema is based on the widely adapted industry standard eXtensible Markup Language (XML) which is used to formulate the Query Message/Response Message (QM /RM).

For the QA/QW in-vehicle application, the RSM provides queue relevant information such as back of queue, front of queue, queue build-up and dissipation rate, average vehicle speed in queue etc. To support a high-fidelity application, queue information at a lane-level is required in RSM. This can be accomplished for a known location such as a work zone for which lane level map data with lane closure information is provided in the RSM. For a low-fidelity application, queue information is generated at a road level where traffic congestion / queue formation could be in any lane.

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List of Acronyms

ABS	Anti-lock Braking System
BoQ	Back of Queue
CAMP	Crash Avoidance Metrics Partners LLC
CV	Connected Vehicles
CV PFS	Connected Vehicles Pool Fund Study
DSRC	Dedicated Short Range Communication
EDCM	Event Driven Configurable Messaging
ETSI	European Telecommunications Standards Institute
FHWA	Federal Highway Administration
FoQ	Front of Queue
GPS	Global Positioning System
HCM	High Capacity Manual
HV	Host Vehicle
INFLO	Intelligent Network Flow Optimization
IOO	Infrastructure Owner Operator
OBU	Onboard Unit
QA/QW	Queue Advisory / Queue Warning
QM	Query Message
RM	Response Message
RSU	Roadside Unit
RSM	Road Safety Message
TMC	Transportation Management Center
USDOT	United States Department of Transportation
V2I	Vehicle-to-Infrastructure
V2I-2	Vehicle-to-Infrastructure Consortium 2
XML	eXtensible Markup Language

1 Introduction

This document develops the requirements for a Queue Advisory / Queue Warning (QA/QW) system. The requirements are developed as part of the Event Driven Configurable Messaging (EDCM) Project in cooperation with the Connected Vehicle Pooled Fund Study (CV PFS) Project on Vehicle-to-Infrastructure (V2I) Queue Advisory / Warning Concept and Design Project. The EDCM Project was conducted by the Crash Avoidance Metrics Partners LLC (CAMP) Vehicle-to-Infrastructure 2 (V2I-2) Consortium, consisting of Ford Motor Company, General Motors LLC, Hyundai Motor Group and Toyota, in cooperation with the Virginia Tech Transportation Institute. The Project was sponsored by the Federal Highway Administration (FHWA) through Cooperative Agreement DTFH6114H00002.

1.1 Project Description

Both vehicle operators and Infrastructure Owner Operators (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.

The EDCM framework operates within the larger connected vehicle (CV) environment, which includes supporting communication infrastructure, security protocols and privacy management techniques required for EDCM to function. EDCM provides a dynamically reconfigurable two-way messaging scheme between EDCM equipped CVs and Transportation Management Centers (TMC) to identify events and road conditions that potentially impede the safety and mobility of the traveling public. It enables a TMC to request information in specified areas regarding current conditions at varying rates and time of day. EDCM-equipped CVs then provide vehicle dynamics and status data in response. A congested road segment or 'queue' of vehicles is one example of such an event. The QA/QW system detects queues and provides relevant information about the queue to the CV in-vehicle application to determine an appropriate action.

1.2 Purpose and Scope of the Document

This document establishes the requirements for a QA/QW system and describes its operation under the EDCM framework. The analysis describes the use of CV data, Traffic Sensor data and Third-Party data in determining potential queue formation and formulating actionable information for dissemination to the CV in-vehicle application as well as unequipped vehicle operators.

1.3 Organization of the Document

This document is organized in the following manner. Section 2 describes the background and use cases for the QA/QW system using EDCM from the perspective of the TMC. Section 3 describes QA/QW system behavior for high-fidelity and low-fidelity applications. Section 4 provides QA/QW system requirements from the perspective of a

TCM operating EDCM and for the in-vehicle application. Section 5 summarizes of the requirements detailed in this document.

2 Queue Advisory / Queue Warning

As suggested in the United States of Transportation (USDOT) published Concept of Operations Document for the Intelligent Network Flow Optimization (INFLO) [1][2][3], the QA/QW system informs vehicle operators of queue ahead to proper action. This section provides QA/QW system concept.

2.1 Traffic Congestion Categories

The change in flow of traffic and congestion is viewed differently by traffic engineers of different regions[1]. The flow of traffic is categorized into the following four categories.

1. Free Flow - The flow of traffic on a given roadway segment is classified as free flow when the average speed of the vehicles in that segment is greater than 70% of the posted speed limit.

2. Moderate Congestion - The flow of traffic on a given road segment is classified as moderately congested when the average speed of the vehicles in that segment is between 50% and 70% of the posted speed limit.

3. Heavy Congestion - The flow of traffic on a given road segment is classified as heavily congested when the average speed of the vehicles in that segment is between 25% and 50% of the posted speed limit.

4. Crawling Traffic - The flow of traffic on a given road segment is classified as crawling when the average speed of the vehicles in that segment is below 25% of the posted speed limit.

2.1.1 Traffic Congestions and Incident Scenarios

The areas where a congestion occur can be categorized into two general scenarios as described in the sections below.

2.1.1.1 Congestion Caused by a Known Incident or at a Known Location

The cause and location of this type of congestion is generally known to the traffic operators. Some examples are:

- Congestion caused by a work zone / construction
- Congestion at or near an exit ramp
- Congestion at or near an entrance / on ramp
- Congestion at or near freeway interchanges

2.1.1.2 Congestion Caused at an Unknown Location

The cause and location of this type of congestion is generally not known. Some examples are:

- Congestion caused by weather related incidents

[1] Based on notes from stakeholder workshops conducted at four different districts of VADOT

- Congestion caused by an accident or due to a broken-down vehicle
- Congestion caused by gawkers

2.2 CVPFS V2I QA/QW Concept and Design

The objective of the CV PFS Project[4] is to a develop high-level design for V2I QA/QW applications for future development and testing efforts using best possible combinations of:

- Data from connected vehicles in near real-time
- Data from infrastructure (e.g., roadside sensor data)
- Data from third-party and other external sources

A conceptual diagram of data flow from various entities is shown in Figure 1. The TMC queue detection system queries CVs for relevant data, aggregates the CV data with infrastructure and third-party data to generate actionable information for dynamic message signs and QA/QW specific RSMs for use by the in-vehicle application.

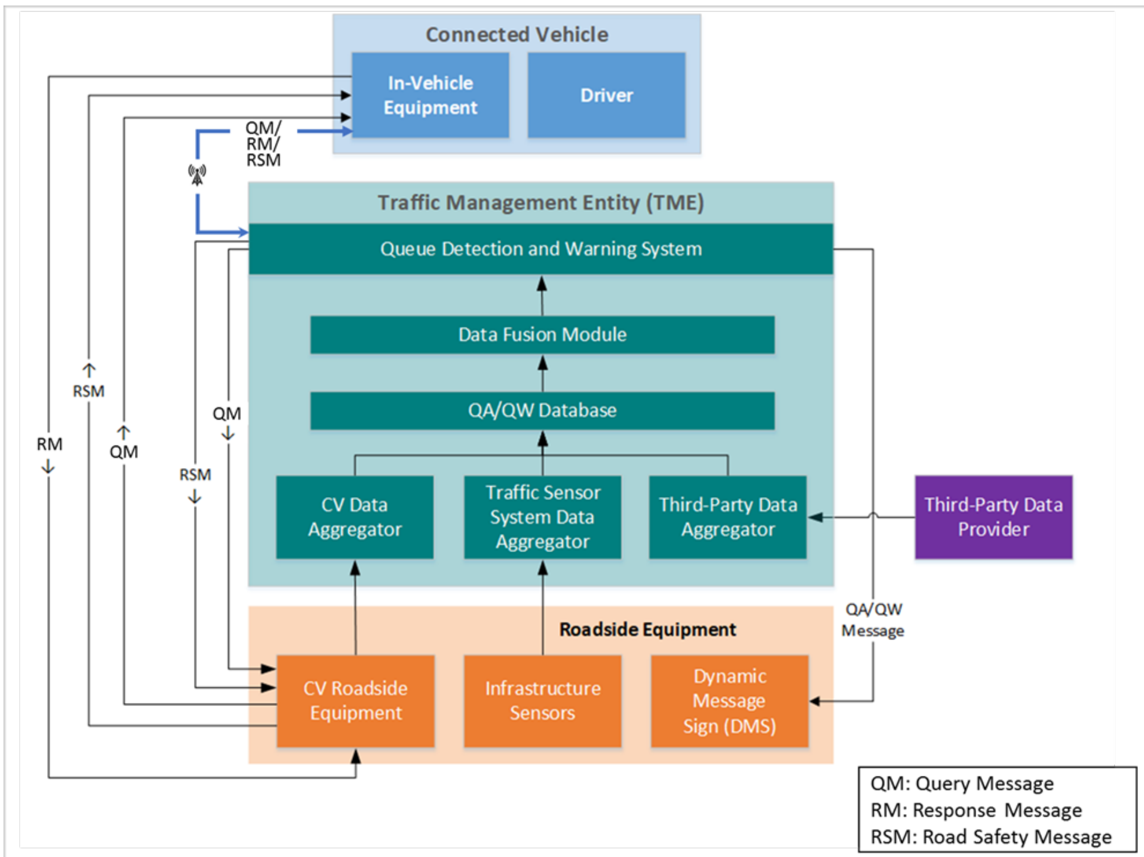

Figure 1: QA/QW System Data Flow Diagram

2.2.1 V2I QA/QW Use Cases

In this subsection, various use cases for QA/QW are described for developing system and onboard application requirements. Various data sources used for queue detection significantly differ in:

- Spatial and temporal resolution
- Latency
- Location referencing
- Queue detection accuracy
- Queue prediction capability

The following operational scenarios are considered using data from various sources based on:

- Infrastructure data only
- Third-party data only
- Infrastructure and Third-party data
- Infrastructure and CV data
- Infrastructure, CV and Third-party data

The formation of queues can be either at known locations and times or at unexpected locations and times.

2.2.2 Queue Formation, Queue Detection and Detection Improvement

Variations in queue structure, methods for detecting queues and potential means to improve detection using CV data are described in this section to identify QA/QW system needs and develop requirements. Examples of various queue formations are shown in Figure 2. In the first illustration, free-flowing traffic slows down as it approaches the back of the stopped queue (BoQ). In the second illustration, the queued traffic experiences stop-and-go conditions forming a slow-moving queue before reaching the front of the queue (FoQ), thus extending the BoQ further towards the upstream traffic. In the third illustration, this condition repeats several times further extending the BoQ location upstream.

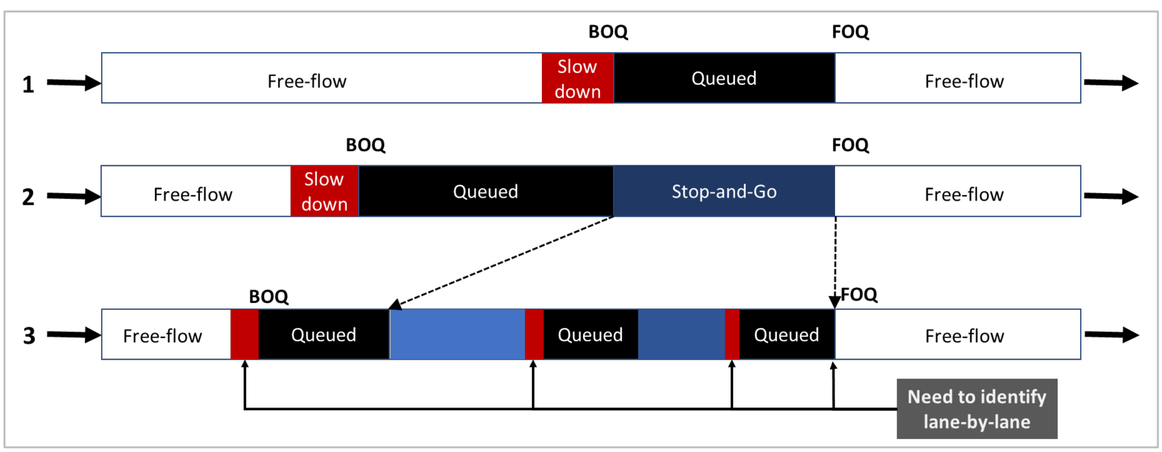

Figure 2: Various Queue Formations

Figure 3 shows a typical method used for queue detection using vehicle speed, speed thresholds and vehicle density. The computations shown in the figure are made by the traffic management entities for their region and local needs.

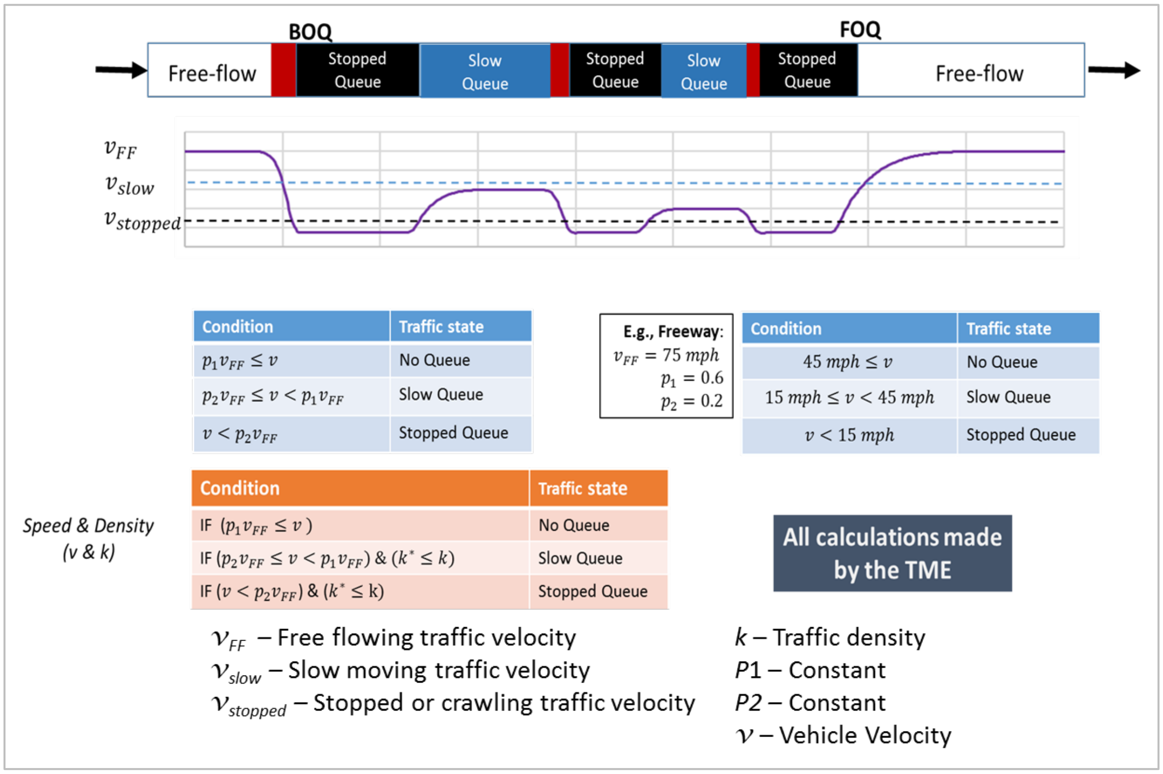

Figure 3: Queue Detection

The Figure 4 shows how specific data from specific location from CVs can improve the queue detection by the TMC.

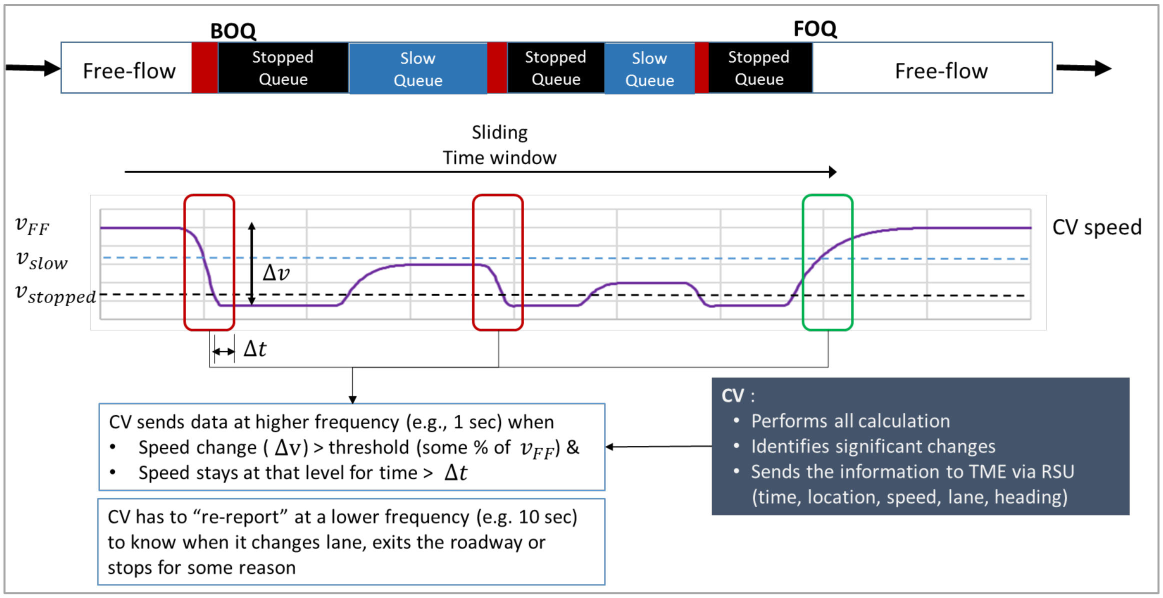

Figure 4: Improvement in Queue Detection Using CV DATA

CV provides vehicle speed, position and heading under various conditions at different frequency to the TMC. It can also report speed change (△v) when a certain threshold is crossed as specified by the TMC in data reporting trigger criteria. This allows the TMC to determine queue formation and dissipation due to significant change in speed at a lane level from vehicle speed, position and heading information. The CV can provide the information at a different rate for TMC to determine whether the CV is approaching the BoQ or is inside the queue. It should be noted, however, that the TMC requested response frequency from the CV is also dependent on the type of communication link between the TMC and the CV and available resources for processing by the CV. Though in general, CVs contain sufficient processing power to generate the requested data at the required rate.

3 Queue Advisory / Queue Warning System Behavior

3.1 QA/QW Application Fidelity

The traffic flow is disrupted and delayed at a work zone because the traffic capacity and the vehicle speed are lower at the work zone section than at other portions of the roadway. Traffic delays at a work zone include delays caused by deceleration of vehicles while approaching the work zone, reduced vehicle speed through the work zone, time needed for vehicles to resume freeway speed after exiting the work zone, and vehicle queues formed at the work zone.

A certain section of roadway where demand exceeds available capacity and creates congestion. The Year 2000 Highway Capacity Manual (HCM) [5] defines a Queue as: "A line of vehicles, bicycles, or persons waiting to be served by the system in which the flow rate from the front of the queue determines the average speed within the queue. Slowly moving vehicles or people joining the rear of the queue are usually considered part of the queue. The internal queue dynamics can involve starts and stops. A faster-moving line of vehicles is often referred to as a moving queue."

Given the need to inform and warn the operators approaching the back of the queue in a work zone, two levels of in-vehicle QA/QW application fidelity are defined based on information from the infrastructure.

In defining the level of fidelity for QA/QW system, it is assumed that the TMC has the following information.

1. The TMC has road-level maps of locations that may suffer from congestion / slow down. The TMC knows the location of highway splits and merges, exits, and entry ramps and posted speed limits.
2. The TMC has detailed information about the planned work zones and planned traffic interruptions, including their locations and speed limits
3. TMC can measure traffic conditions using inductive loops or other roadside sensors and knows their accuracy and latency

3.1.1 High-Fidelity

A high-fidelity system provides lane-specific traffic congestion / queue information to approaching motorists to inform / warn them to take appropriate action.

Scenario: Work zone (reduced capacity)

Assumption: The TMC has lane-level work zone map data that includes:

- Cause and sub cause codes (for informational purpose as defined in European Telecommunications Standards Institute (ETSI))
- Number of lanes closed and open for traffic
- Start of work zone (Reference Point in latitude/longitude/elevation)

- Heading – vehicles approaching the work zone
- Lane-level map of approach lanes (~600m)
    - Note: the map of approach lanes may need to be extended based on anticipated Back of Queue (BoQ) position
- Location of start of lane closure (start of taper)
- Speed limits
    - Posted speed limit of the roadway
    - Work zone speed limit (reduced speed limit)
- The following is determined by the TMC by aggregating data from CVs, roadside sensors and other sources for each lane:
    - Average speed in queue
    - Back of Queue (BoQ) position for each lane in latitude, longitude and elevation at better than 100m resolution
    - Optionally the Front of Queue (FoQ) for onboard vehicle application to determine estimated time to go through the queue
    - Shockwave speed of the queue for onboard vehicle application to determine BoQ position based on its location and speed for generating appropriate information

3.1.2 Low-fidelity

A low-fidelity system provides road-level traffic congestion / queue information to approaching motorists to inform/warn them to take appropriate action.

Scenario: Reduced roadway capacity caused due to an incidence or an anomaly

Assumptions: In the case where traffic congestion leading to a queue is at an unknown or unexpected location, the TMC does not have map data for each lane, only road-level information such as the number lanes is available. Also, the TMC has limited information about the traffic congestion from a 3rd party source.

- The TMC has following limited information:
    - Number of lanes
    - Normal speed limit
- The TMC to determine:
    - Traffic backup/congestion from external sources (e.g., police report, reported by callers, etc.)
    - Average speed of vehicles in queued/congested area (road level)
    - Back of Queue (Congestion) – approximate latitude/longitude/elevation may be at 1/10th mile resolution
- Data elements required for in-vehicle QA/QW application for RSM is defined Table 1.
- The RSM is transmitted at 1Hz

4 Queue Advisory / Queue Warning System Requirements

The TMC and in-vehicle application requirements for a QA/QW system are presented in this section.

4.1 EDCM at the TMC

The EDCM system operates within the larger CV environment which includes supporting communications infrastructure, security protocols and privacy management techniques required for EDCM to function, but not detailed in this document. EDCM enables a TMC to request information from CVs equipped with EDCM capabilities in specified areas regarding current conditions at varying rates and time of day. EDCM equipped CVs then provide vehicle dynamics and status data in response using a flexible messaging schema.

At the TMC, QA/QW consists of two subsystems.

1. The TMC utilizes the EDCM framework to send QM(s) requesting data relevant to its queue detection algorithm(s) as described in subsection 2.4.2. These QMs can specify a geofenced location(s) of interest, including direction of travel, as well as sample time interval(s) in the message trigger criteria as described in subsection 4.3.1. The TMC aggregates RMs received from EDCM-equipped CVs and combines the information with data from other sources, such as external roadside sensors and third-party data when available, for analysis to determine traffic congestion / queue location(s).

2. Once a queue is determined, the TMC returns relevant information to all CVs using a Road Safety Message (RSM). This information may also be distributed to non-connected vehicles using Dynamic Message Signs or other conventional techniques (The J2945/4 RSM specification is under development at SAE). The RSM data elements required to support the in-vehicle QA/QW application are described in subsection 4.7.1.1.

4.2 Data Request in a Query

The Query Message (QM) sent by the TMC is based on a well-defined data dictionary, known to both the connected vehicle and the infrastructure system. In this initial design, 23 different vehicle data elements or status information can be requested in a query.

The following vehicle data can be requested in a QM:

- **Basic information:**
    - Vehicle type, pseudo Vehicle ID
- **Position and dynamics:**
    - Position, heading, speed, acceleration, yaw, steering wheel angle

- **Status (safety):**
  - Activation of brake, traction control, stability control
- **Status (weather):**
  - Exterior lights, wiper position, external air temperature

A QM can request how and under what conditions to provide Response Message (RM) data to the TMC, for example:

- **Instantaneous value**:
  - vehicle speed, external air temperature or wiper position
- **Composite or averaged data:**
  - average of vehicle speed within given time period or distance traveled
- **Conditional:**
  - Based on certain vehicle status
  - Based on periodic update
  - Based on demand
  - Based on pre-samples
- **Within a region of interest (geofenced):**
  - Within a polygon
  - Within a circle
  - Within travel distance from specific location and direction
  - From → To location

4.3 Flexible Messaging Schema

The EDCM flexible messaging schema is based on a widely adapted industry standard eXtensible Markup Language (XML) [6] which is used to formulate the QM/RM.

4.3.1 Formulating a Query Message in XML

A QM is formulated by proper user input of values corresponding to XML tags. A root element (or tag) <qmFrame> must be used to formulate a QM. As defined, an XML document has exactly one single root element. It encloses all the other elements and is therefore the sole parent element to all the other elements. Following elements are available within the root element for defining a QM.

- **Event Message:** <eventMsg> This is a required element within <qmFrame> that describes event for which this query is generated. This element has several associated attributes to provide event specific information in the query message. This element contains required and optional attributes listed in Table 1.

Table 1: <eventMsg> - Supported Elements and Attributes

Element/Attribute Name	Description	R / O R=Required O=Optional
eventID	A unique identification number	R
msgDateTime	Message timestamp	R
vehType	Vehicle type	O
eventInfo	Event information / description	O
rmCommType	Communication method for query response	R
msgType	Query message type - iamHere, query, response or inform	R
msgPriority	Priority for message processing	O
vehResponsePct	Requested % of vehicles respond to this query	O
vehID	Unique vehicle ID	O
cCode	Cause Code (see ETSI cause codes)	O
scCode	Sub cause code (see ETSI sub cause codes)	O
msgCount	Message Count is incremented to indicate a new message for the same event ID	O
schemaVer	XML schema version number	R

- **Vehicle Data Request:** <dataRequest> This required element enables requesting data from participating EDCM vehicles, such as vehicle speed, position, heading, etc. In this initial design, 23 different vehicle measurements/parameters are supported for data request in QM. Additionally, the number of pre- and post-triggered samples for vehicle data and sampling interval can also be provided in the data request. Table 2 lists required and optional attributes supported in this element.

Table 2: <dataRequest> - Supported Elements and Attributes

Element/Attribute Name	Description	R / O* R=Required O=Optional
dataName	Vehicle data parameters name	R
dataAvgName	Vehicle data parameters name for data averaging	O
preTrigSamples	Number of pre trigger samples	O
postTrigSamples	Number of post trigger samples	O
intervalTime	Sampling time interval	O
intervalDistMet	Sampling interval by travel distance (meters)	O
timeDur	Total sampling time duration	O

- **Query Message Duration:** <qmDur> This is an optional element that defines duration for which the QM is valid using start and end date and time values as listed in Table 3.

Table 3: <qmDur> - Supported Elements and Attributes

Element/Attribute Name	Description	R / O* R=Required O=Optional
startDate	Start date	O
endDate	End date	O
startTime	Start time	O
endTime	End time	O

- **Query Message Action:** <qmAction> This is an optional element that provides a mechanism to start or stop the active query message at a specified time for processing by the participating vehicles. See Table 4.

Table 4: <qmAction> - Supported Elements and Attributes

Element/Attribute Name	Description	R / O* R=Required O=Optional
Action	Start | Stop	O
Time	Time represented in date and time format as shown in example	O

- **Geo Fenced Regions:** <gfRegion> This is an optional element used to define a geographic region of interest (geofence) for which the response is sought from the participating vehicles. Following four ways a region can be specified in a query.
  - Polygon
  - Circle with specified radius
  - Drive distance from a desired location in specific direction
  - From location → To location

In addition, for any of the specified regions of interest, an elevation can also be specified using this element to further narrow the region. See Table 5.

Table 5: <gfRegion> - Supported Elements and Attributes

Element/Attribute Name	Description	R / O* R=Required O=Optional
gfRegionElev	Optionally, to define elevation for any of the following regions of interest. It allows in specifying road segments at certain elevation	O
poly	To define a region of interest as a polygon using a list of nodes represented in degrees of latitude and longitude	O
circle	To define a circular region of interest by specifying center of a circle and radius	O
from2toLocation	To define From → To location of travel	O
driveDistKm	To define a region of interest by driving distance from a specified location in specific direction	

- **Query Message Trigger**: <qmTrigger> This is an optional element that allows a user (TMC) to set various conditions for triggering the QM using logical and Boolean operators. Multiple conditions can be set in a QM for triggering. For example, a QM may request vehicle status information such as speed, position, traction control system status only from a certain vehicle type when external air temperature is near freezing (37° F or 2.7° C) as shown in example. Table 6 lists the supported elements used for a trigger. Appendix A shows list of supported vehicle parameters that can be used along with logical and temporal conditions for reporting requested vehicle status information.

Table 6: <qmTrigger> - Supported Elements and Attributes

Element/Attribute Name	Description	R / O* R=Required O=Optional
Vehicle Parameters	See list in Appendix A	O
dataCond	Logical and Boolean conditions	O
timeDur	Time duration for trigger condition	O

4.3.2 Example Query Message

In the QA/QW system, a TMC requests vehicle speed, position and average pre-triggered vehicle speed to determine speed drop as the upstream vehicles are approaching the BoQ. Once the vehicle has slowed down in congestion, the query also requests to provide speed and position every time it has traveled 160m (1/10th of a mile) to get more precise information about the queue within 10 miles of a geo-fenced region as defined in geo fence.

```
<?xml version="1.0" encoding="UTF-8"?>

<!--  Use case - Queue Advisory / Queue Warning            -->
<!--   Query Message from TMC                              -->
<!--   ==============  Query Message ================  -->


<qmFrame>
<!--Event-->
       <eventMsg eventID="23" msgDateTime="2019-11-23T06:00:00" vehType="1"
              eventInfo="Queue Detetcion" rmCommType="cellAndDSRC"
              msgType="query" msgCount="1" msgPriority="0" schemaVer="1.0">
       </eventMsg>

<!--Data request from CV-->
       <dataRequest><!--Report every 1/10th mile-->
              <provide dataName="speedMps" intervalDistMet="160"/>
              <provide dataName="vehPos"/>

              <!--At time of trigger, averaged speed change-->
              <provideAvg dataAvgName="speedChangeMps" preTrigSamples="10"
               intervalTime="00:00:01"/> <!--Avg of pre trig samples-->
       </dataRequest>

<!--Valid duration for query message -->
       <qmDur startTime="06:00:00" endTime="10:00:00"></qmDur>
```

```
<!--Geo Reference-->
       <gfRegion>   <!--From GW Parkway for 16km drive distance-->
              <driveDistKm>
                     <from latDeg="38.830333" longDeg="-77.043948" distKm="16"
                      headingDeg="0" toleranceDeg="45"/>
              </driveDistKm>
       </gfRegion>

<!--Query message trigger when speed change (drop) is GE 70% in LE 10sec -->
       <qmTrigger>
              <when speedChangePct="70.0" dataCond="GE"/>
              <when timeDur="PT10S" dataCond="LE"/>
       </qmTrigger>
</qmFrame>
```


4.4 EDCM In-Vehicle

An EDCM-enabled CV is equipped with appropriate hardware and application software to support wireless information exchange with the TMC. Two-way communication for data exchange is an integral part of the EDCM System for short-range and/or long-range communication. As shown in Figure 5, a typical in-vehicle system to enable EDCM consists of:

- Short-range communication device – Dedicated Short-Range Communication (DSRC)
- Long-range communication device – cellular (e.g., 4G LTE)
- Global Positioning System (GPS)
- On-Board Unit (OBU) – computing platform for processing queries and application
- Controller Area Network (CAN) for vehicle data
- Driver Vehicle Interface (DVI) system

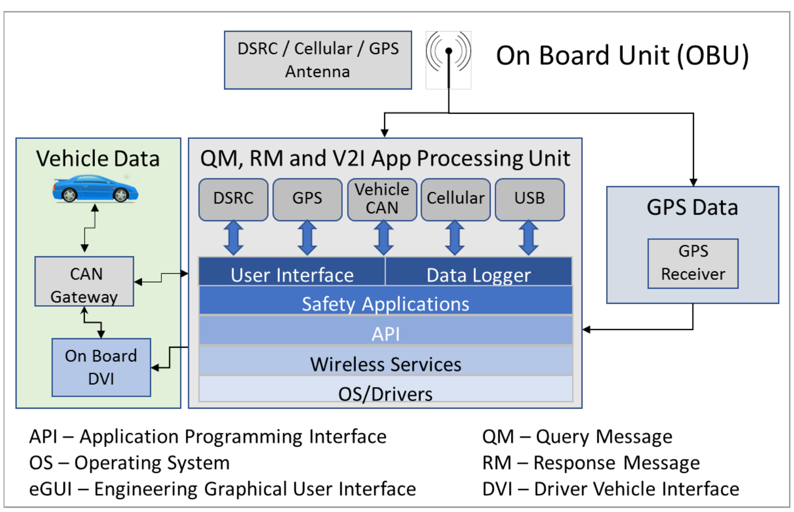

Figure 5: EDCM-Enabled Vehicle System

4.4.1 Query Response

Once a query message is generated and transmitted, EDCM-enabled vehicles that receive it will process it as specified by the QM if the data and vehicle resources are available.

- Vehicles may receive multiple queries from multiple TMCs at any given time
- Since QMs use the pre-defined data dictionary, the same XML schema is used in the vehicle to process the QM and generate a RM. It is a requirement that the schema version used in generating the QM be included in <eventInfo>.
- The QMs are processed based on message priority, vehicle position relative to any geo-fence criteria and other trigger conditions to formulate RMs
- For elements of the QM that the vehicle does not recognize, no associated response is formulated. This could occur due to a different version of schema (data dictionary) between TMC and CV.
- For elements of the QM that the vehicle recognizes, the vehicle may or may not generate a response, depending upon the element queried and conditions
- 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

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 requested data or has limited processing capability to formulate the queried response. If multiple QMs are received at once, the EDCM-enabled vehicle will respond to QMs according to the priority associated with each received QM.

4.5 Network/Communication Requirement

This subsection describes the communication requirements for an EDCM system. Based on the EDCM communication schema, the TMC may communicate with EDCM-enabled vehicles using different communications methods as shown in Figure 6. Short-range and/or long-range communication may be utilized to broadcast QMs and receive RMs as available and appropriate.

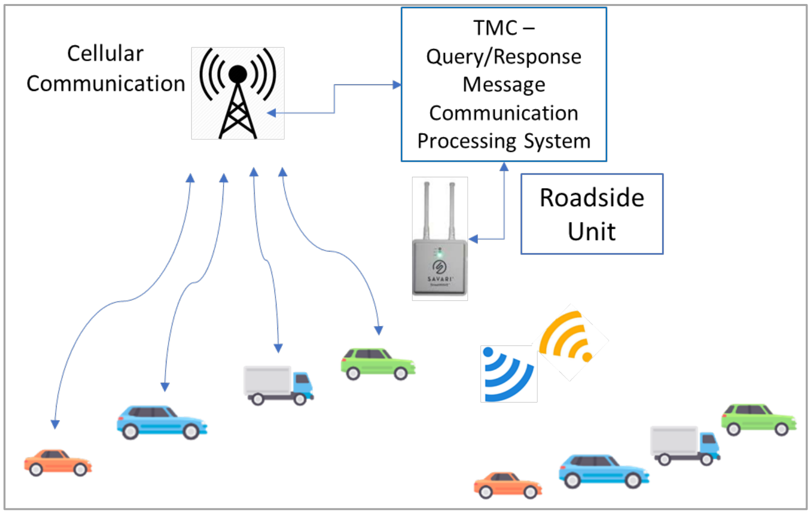

Figure 6: EDCM System Communication with CV

Long-Range: Direct Communication Between TMC and CV

The EDCM system may establish direct communication with the EDCM-enabled vehicle over a long-range using cellular communication for information exchange. When using this mode of communication, the TMC may experience the delays/latencies in information exchange due to latency introduced by the cellular communication system, which could be up to few seconds.

Short-Range: Direct Communication Between RSU and CV

In this communication schema, information exchange between the TMC and CV is carried out in two steps. The TMC communicates QMs to Roadside Units (RSUs) along a road segment using backhaul communications. The RSU then uses low latency short-range wireless communication to broadcast QMs to the vehicles within its transmission range. In this mode, the TMC may experience following delay/latency.

- Depending upon the type communication backhaul between the TMC and the RSU, the latency can be introduced in communicating the QM to the RSU including information processing in RSU
- Similarly, latency can be introduced in forwarding the received RM from RSU to TMC

In addition to latency associated with communication, there can be in-vehicle processing delay. This can be caused by vehicle system processing priority for more safety critical system such as ABS or a traction control system and available resources to process QM from TMC.

4.6 In-Vehicle QA/QW Application

The purpose of the in-vehicle QA/QW application is to provide relevant information and potentially alert the vehicle operator in a timely manner to take appropriate action prior to reaching the BoQ. As described earlier, based on the level of fidelity of information provided in the RSM from the TMC, the in-vehicle application combines the RSM information with vehicle dynamics data to inform the driver of the upcoming situation followed by a warning, if warranted. A high-level application flowchart is shown in Figure 7.

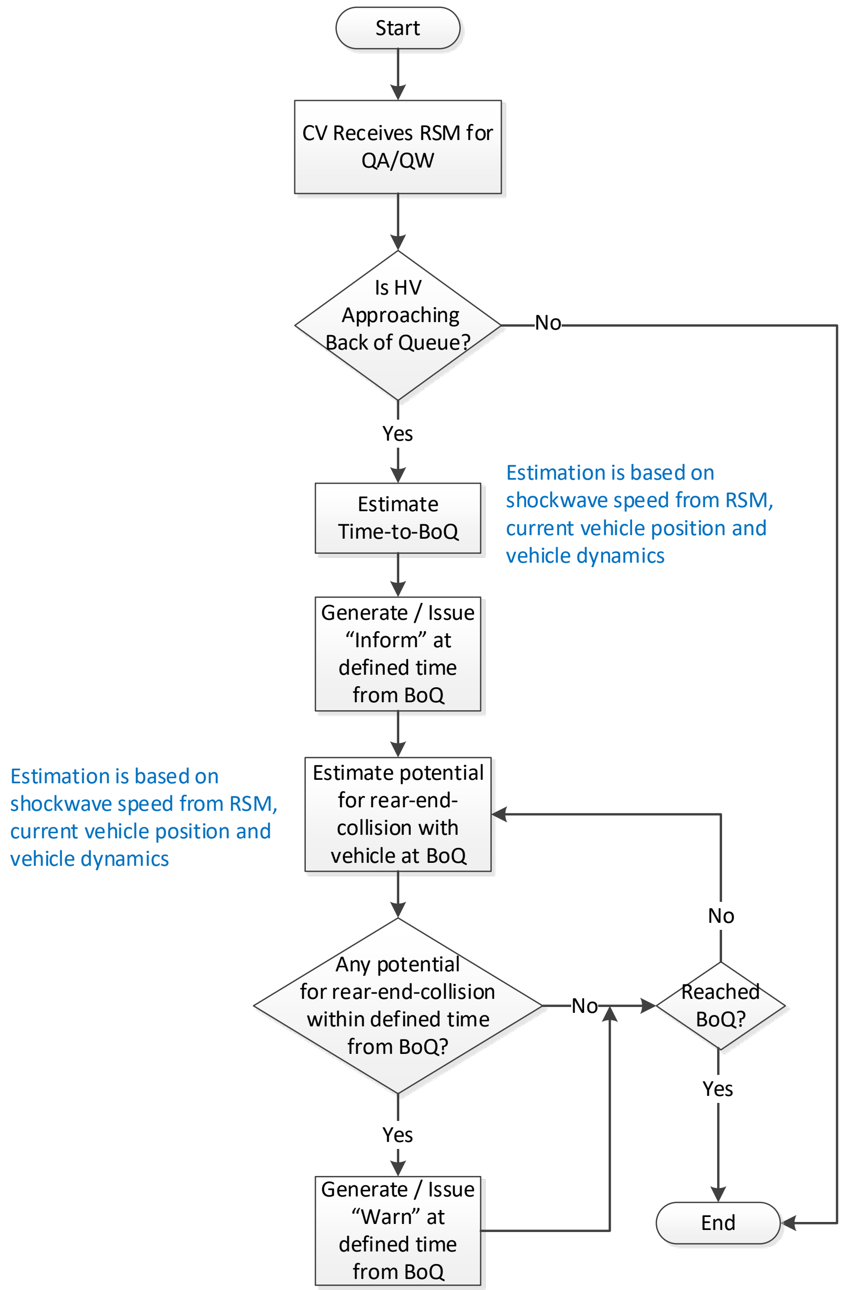

Figure 7: Flow Diagram for In-Vehicle QA/QW Application

4.6.1 Estimating Inform and Warn Distances from BoQ

The process for generating "Inform" and "Warn" zones for the in-vehicle QA/QW application is presented here. The suggested "Inform" zone is based on configurable pre-defined time (distance) for the host vehicle to reach the BoQ and distance from start of the zone. The pre-defined time to reach the BoQ considers vehicle dynamics (vehicle type, laden vs. unladen, vehicle speed, appropriate deceleration rate, etc.) based on shockwave speed in the RSM and an estimate of operator perception reaction time. The start of "Warn" zone is generated based on estimated time (distance) to the BoQ based on shockwave speed, vehicle dynamics and vehicle position (lane or road level as available). Figure 8 illustrates the "Inform" and "Warn" zone concept. In the figure, the start of "inform" zone is indicated at t_{Istart} and ending at t_{Iend} and the "Warn" zone starts at the end of "Inform" zone until reaching the estimated BoQ.

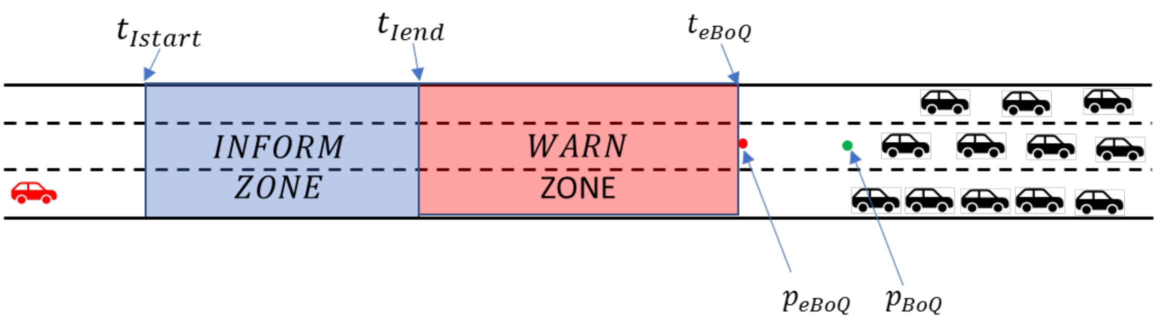

Figure 8: Estimation for "Inform" and "Warn" Zones

The distances for the start of the "Inform" and "Warn" zones are based on time as follows:

$$d_{inf} = t_{inf} * v_{hv}$$
$$d_{warn} = t_{warn} * v_{hv}$$

Where;

d_{inf} = Distance to start of inform zone. Inform Zone is a calculated segment of the roadway where the in-vehicle application issues and maintains "Inform" to the operator.

d_{warni} = Distance to start of warn zone. Warn zone is a calculated segment of the road where the in-vehicle application issues and maintains "Warn" to the operator

t_{inf} = Configurable time threshold for start of "Inform" zone

t_{warn} = Configurable time threshold for start of "Warn" zone

v_{hv} = Current speed of the host vehicle (*hv*)

t_{eBoQ} = Time (distance) for Host Vehicle (HV) to reach estimated BoQ position (P_{eBoQ})

P_{BoQ} = Current position of BoQ

P_{eBoQ} = Estimated BoQ position

4.6.2 Estimating Distance to BoQ

The process for estimating distance for HV from current position to estimated BoQ is presented here. Figure 9 illustrates a scenario where a host vehicle is approaching a region with vehicles in queued state. Since the BoQ point moves at shockwave speed of v_{sw}, the *hv* will reach the BoQ at p_{eBoQ}. As shown in Figure 9, distance for *hv* to reach BoQ can be calculated as:

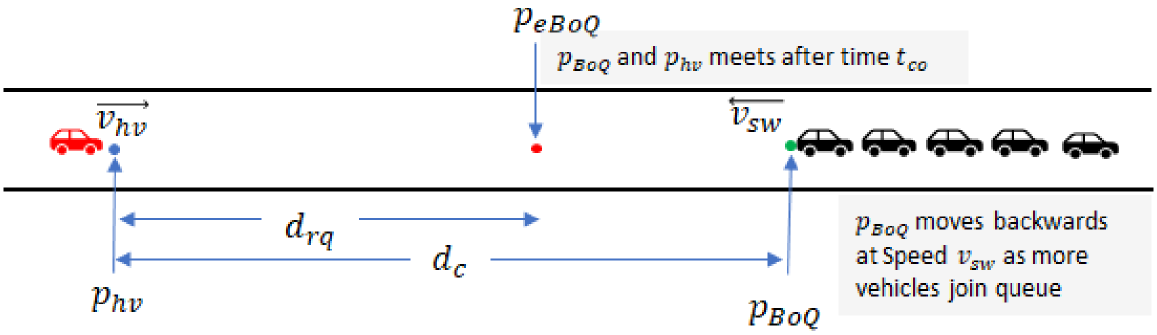

Figure 9: Estimating HV Distance to BoQ

$d_{rq} = v_{hv} * d_c / (v_{hv} + v_{sw})$
$t_{BoQ} = d_{rq} / v_{hv}$

Where;

p_{hv} = Current position of HV
p_{BoQ} = Current position of BoQ
p_{eBoQ} = Estimated position of BoQ, where p_{hv} meets p_{BoQ}
d_c = Computed straight-line distance between the HV and BoQ in meters
v_{hv} = HV speed in m/s
v_{sw} = BoQ Shockwave (queue growth rate) speed in m/s. Positive for upstream and negative for downstream traffic
t_{BoQ} = Time in s when the HV meets the BoQ
d_{rq} = Distance to estimated BoQ. It is negative if HV speed <= BoQ shockwave speed.

4.7 In-vehicle QA/QW Application Requirements

The RSM data elements required to support QA/QW are presented here.

4.7.1 Data Elements for Road Safety Message (RSM)

The J2945/4 RSM specification under development at SAE consists of two containers: A “Common” container and an “Application” container. The Common container defines data elements that are common to all V2I in-vehicle applications. The Application container defines data elements that are application specific, e.g., Reduced Speed Zone (RSZ) container, Curve container. To support QA/QW application in RSM, the EDCM Project team proposed adding a ‘Queue’ container in RSM. The proposed “Queue” container uses many of the existing data elements already defined in RSM and in DSRC J2735 for other applications. Proposed elements for “Queue” container are described in the following section.

4.7.1.1 Queue Container

- **Road Surface Condition** – Current road condition e.g., dry, wet, snow

- **Queue Status List –** A list of queue status for each applicable lane
- **Associated Lane –** an *RSMLane* data type that describes lane geometry. Lane geometry allows in-vehicle application for determining lane position of the HV. If the laneID is set to 0, lane-level information is not available, and the application considers road geometry.
- **Queue Ahead Warning –** This Boolean data element indicates the presence or absence of a queue ahead. This element is defined in RSM (under *congestionInfo*). For lanes that do not have a queue, this value would be set to False. It provides additional information to the application for vehicle operator.
- **Traffic Flow –** Provides traffic flow type as an additional information for the vehicle operator. The traffic flow types are described in subsection 2.1.
- **Back of Queue (BoQ) Position –** Provides estimated position of the back bumper of the last vehicle in the queue. The accuracy of the estimation depends on the level of information available to the TMC.
- **BoQ Position Update Time –** The date and time at which the BoQ position information was last updated.
- **BoQ Shockwave Speed –** This element provides the rate at which the BoQ is moving. A negative value indicates rate at which the queue is growing towards the upstream traffic.
- **Front of Queue (FoQ) Position –** Provides estimated position of the front bumper of first vehicle in the queue.
- **FoQ Shockwave Speed –** This element provides the rate at which the FoQ is moving. A positive value indicates the rate at which the queue is dissipating towards the downstream traffic. The rate of zero indicates the FoQ is stationary.
- **Queue Confidence –** Provides average confidence (in %) of the estimation, queue speed, FoQ and BoQ positions and shockwave speeds.
- **Average Queue Speed –** Indicates the average speed of the vehicles in the queued section of the roadway.

Table 7 lists the data elements for in-vehicle QA/QW application in ‘Common’ and ‘Queue’ Containers.

Table 7: Data Elements for In-Vehicle QA/QW Application

Common Container				
Data Element	**Data Type**	**Application Fidelity** R = Required O = Optional		**Description**
		High	**Low**	
Message Version	As 'version' in RSM.Version	R	R	For compatibility
Event Info	As 'eventInfo' in RSM. EventInfo	R	R	Contains information related to event start/end date/times, recurrence, cause codes
Event ID	As 'eventID' in DSRC.TemporaryID	R	R	Randomly assigned temporary ID for the event
Cause Code (ETSI)	As 'causeCode' in RSM.CauseCOde	O	O	Cause code from list of event codes defined in ETSI
Sub Cause Code (ETSI)	As 'causeCode' in RSM.SubCauseCode	O	O	Sub cause code from list of event codes defined in ETSI
Region Info	As 'RegionInfo' sequence in RSM • applicableHeading • speedLimit	O	O	Contains heading, reference point, speed limit, etc. for map matching purpose
Roadway Geometry	As 'AreaType' sequence in RSM • roadwayGeometry • broadRegion	O	O	To define regions of interest

Queue Container				
Data Element	**Data Type**	**Application Fidelity** R = Required O = Optional		**Description**
		High	**Low**	
Surface Condition	As 'surfaceCondition' in RSM.SurfaceCondition	O	O	Enumerated values describing current road condition
Queue Status List	As 'QueueStatusList'	R (Lane Level)	R (Road Level) O (Lane Level)	Sequence of queue status for each lane
Associated Lane	As 'RSMGeometry' as RSMLane • laneID • laneGeometry	R	R	SEQUENCE (Size (1...10) of RSMLanel Lane ID = 0 indicates road level geometry
Queue Ahead Warning	As 'queueAheadWarning' in RSM	O	O	BOOLEAN – Informative
Traffic Flow	As 'trafficFlowStatus'	O	O	0 = Free flow, 1 = Moderate, 2 = Heavy, 3 = Crawling / Standstill
Back of Queue (BoQ)	As 'PositionBoQ'	R	R	Back of Queue position in Latitude and longitude: Micro Degrees, Elevation: 10cm
BoQ Shockwave Speed	As 'ShockwaveSpeedBoQ'	R	O	In +/- 0.2 m/s

Queue Container				
BoQ Position Update Time	As 'BoQUpdateTime' in DSRC.DDateTime	O	O	Time when BoQ position was last updated
Front of Queue (FoQ)	As 'PositionBoQ'	O	O	Front of Queue position in Latitude and longitude: Micro Degrees, Elevation: 10cm
FoQ Shockwave Speed	As 'ShockwaveSpeedFoQ'	O	O	In +/- 0.2 m/s
Queue Confidence	As 'PctQueueConfidence'	O	O	List of average queue confidence level in % for all related measurements - speed, FoQ, BoQ, queue build-up rate
Average Queue Speed	As 'AverageQueueSpeed'	O	O	In 0.02 m/s - Average speed of vehicles in queue

5 Summary

This document develops the requirements for a CV QA/QW system. The QA/QW system detects queues and provides relevant information about the queue to the CVs to determine an appropriate action. The QA/QW system operates under an EDCM framework. EDCM leverages existing CV infrastructure and communications to identify events and road conditions that potentially impede the safety and mobility of the traveling public. A congested road segment or 'queue' of vehicles is one example of such an event.

The EDCM system operates within the larger CV environment, which includes supporting communication infrastructure, security protocols and privacy management techniques required for EDCM to function. It enables a TMC to request information from CVs equipped with EDCM capabilities in specified areas regarding current conditions at varying rates and time of day. EDCM-equipped CVs then provide vehicle dynamics and status data in response using a flexible messaging schema.

The QMs sent by the TMC are based on a well-defined data dictionary, known to both the connected vehicle and the infrastructure system. In this initial design, 23 different vehicle data elements or status information can be requested in a query. The TMC aggregates RMs received from EDCM-equipped CVs and combines the information with data from external roadside sensors and third-party data. In the QA/QW application, if the TMC detects traffic congestion / queue formation, it returns RSM information to all CVs to determine appropriate action. This information may also be distributed to non-connected vehicles using Dynamic Message Signs or other conventional techniques.

Requirements for RSM data to support in-vehicle QA/QW applications varying based on the fidelity of roadway information available. High-fidelity and low-fidelity in-vehicle applications are defined based on available information from the infrastructure. In case of high-fidelity application, the TMC provides queue relevant information at lane-level including lane-level map of locations that may suffer from congestion potentially forming queues at known locations such as to work zones. For cases where the TMC may not have detailed information about the roadway section suffering from slowdown low-fidelity application, data is provided at the road level.

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