
# V2I Queue Advisory/Warning Applications: Concept and Design

# SYSTEM REQUIREMENTS

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# 1. INTRODUCTION

## 1.1. BACKGROUND

The United States Department of Transportation (USDOT) Intelligent Transportation Systems Joint Program Office (ITS JPO) Vehicle-Infrastructure Program has been researching connected transportation systems. Part of this effort has focused on researching and prototyping applications to optimize the safety and mobility performance of the transportation network by integrating infrastructure-based technologies into connected systems.

This document is one of the deliverables prepared for the V2I Queue Advisory/Warning Applications: Concept and Design project. The project is a collaborative effort between the USDOT and the Connected Vehicle Pooled Fund Study (CV PFS) entitled *Program to Support the Development and Deployment of Connected Vehicle Applications*. This CV PFS was created by a group of state, local, and international transportation agencies, and the Federal Highway Administration (FHWA), with the Virginia Department of Transportation (VDOT) serving as the lead agency. The University of Virginia Center for Transportation Studies (UVA CTS) supports VDOT on the pooled fund study, serving as the technical and administrative lead for the effort, and manages all the projects on behalf of the CV PFS and the USDOT.

## 1.2. PURPOSE AND SCOPE OF DOCUMENT

The purpose of this document is to provide high-level systems requirements of the infrastructure-side of a Vehicle-to-Infrastructure (V2I) Queue Advisory/Queue Warning (QA/QW) application. The application utilizes typical technologies and systems deployed by infrastructure owner operators (IOOs)—traffic sensor data and queue and congestion information provided by third-party data providers, married with data provided by vehicles equipped with connected vehicle (CV) technologies—to detect the potential formation of queues on a per lane basis, and provide relevant information about the queue. IOOs can use this information to provide alerts and warnings to motorists approaching the back of a queue through both traditional traveler information devices (e.g., dynamic message signs) and advanced information dissemination devices (e.g., in-vehicle displays).

This document builds upon the *V2I Queue Advisory/Warning Applications: Concept and Design - Concept of Operations*[1] document, which describes the overall concept of how the system developers envision the system to operate. Readers are encouraged to consult this document first to gain a high-level understanding of how the system is expected to operate and function.

The V2I QA/QW system also incorporates the concept of Event Driven Configurable Messaging (EDCM). EDCM is a concept developed by the Crash Avoidance Metrics Partners, LLC (CAMP) Vehicle-to-Infrastructure 2 (V2I-2) Consortium. The consortium consists of representatives from the Ford Motor Company, General Motors, LLC, Hyundai Motor Group and Toyota, in cooperation with the Virginia Tech Transportation Institute. The EDCM concept

[1] *V2I Queue Advisory/Warning Applications: Concept and Design - Concept of Operations.* Texas A&M Transportation Institute. Texas A&M University System, College Station, TX. April 2020.

was developed as part of a project sponsored by the Federal Highway Administration (FHWA) through Cooperative Agreement DTFH6114H0002. The EDCM framework operates within the larger 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 IOOs operating the roadways through a traffic management entity (TME). The TME is responsible for identifying events and road conditions that potentially impede the safety and mobility of the traveling public. EDCM enables a TME 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 V2I QA/QW system detects queues and provides relevant information about the queue to the CV in-vehicle application to determine an appropriate action. A reader can find a more complete description of the EDCM concept in Event-Driven Configurable Messaging (EDCM) Queue Advisory & Queue Warning (QA/QW) System and In-Vehicle Application Requirements[2].

## 1.3. ORGANIZATION OF DOCUMENT

This document is organized in the following manner:

- Section 2 provides a brief review of the concept of operations of the proposed V2I QA/QW system, particularly from the infrastructure viewpoint.
- Section 3 provides the high-level system requirements for the V2I QA/QW data aggregation process.
- Section 4 presents high-level system requirements for fusing data to produce the best estimates of queue attributes.
- Section 5 contains the system requirements associated with the development and use of event-driven configurable messaging subsystem.
- Section 6 provides high-level system requirements for estimating and predicting queue attributes.
- Section 7 contains high-level system requirement for generating queue information messages for both infrastructure and in-vehicle users.
- Section 8 provides high-level system requirements for generating and archiving metrics that agencies can use to assess the accuracy and timeliness of the queue estimates produced by the V2I QA/QW system.

[2]*Event-Driven Configurable Messaging (EDCM) Queue Advisory & Queue Warning (QA/QW) System and In-Vehicle Applications Requirements*. Crash Avoidance Metrics Partners LLC (CAMP) Vehicle-to-Infrastructure 2 (V2I-2) Consortium. June 2020. [DRAFT].

## 2. SYSTEM OVERVIEW

Figure 1 shows a high-level graphical overview of the V2I QA/QW Application. This and following illustrations in this document assume the use of RSU-based, short-range communication between CV and TME. However, the system can also be implemented using cellular based, long-range communication. The illustrated system has four key components: 1) roadside equipment, 2) connected vehicles, 3) third-party data providers, and 4) traffic management entity. Each of these components has several elements. The figure also indicates the data and information flow between system components.

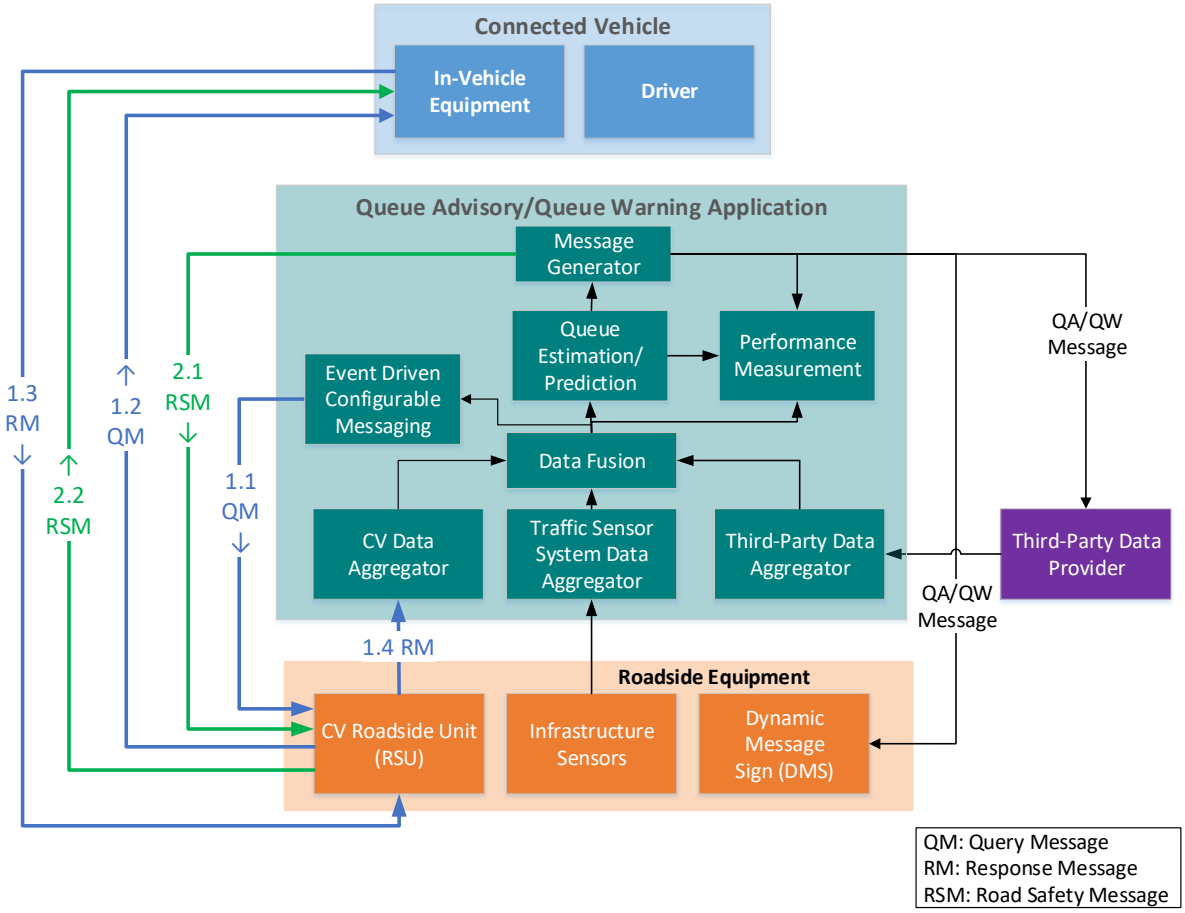


**Figure 1. System Diagram of V2I Queue Advisory/Warning Applications Using Short-Range Communication.**

### 2.1. QUEUE ADVISORY/QUEUE WARNING APPLICATION

The QA/QW Application resides in the TME and is responsible for fusing the data from CV, infrastructure sensors, and third-party data providers and uses the resulting data set for the detection of queues and generation of appropriate queue warning messages.

Once data are received from one of the data sources, it is cleaned (checked for potential outliers, missing data, errors and inconsistencies) and aggregated as needed. The cleaned and aggregated

data are stored in a QA/QW database, and then processed by a data fusion application that takes into account the differences in the spatial coverage, spatial and temporal resolution and location referencing of the data from CV, infrastructure sensors and third-party provider.

Based on these fused data, the TME determines the locations of back of queue (BOQ) and front of queue (FOQ) and additional queue attributes (e.g., speed at the BOQ, average speed in queue and boundaries of zones with stopped, slow, and stop-and-go traffic). The TME is also responsible for the generation of queue warning messages for DMSs, and Query Messages (QM) and Road Safety Messages (RSM) for CVs.

## 2.2. CONNECTED VEHICLE

CV collects high-resolution vehicle operational data that can supplement infrastructure and third-party data, and thereby improve the accuracy and latency in queue detection. Development of ConOps for V2I QA/QW applications is based on the following CV-related assumptions:

- CV is capable of short-range communication with Roadside Unit (RSU).
- CV is also capable of long-range communication with TME.
- CV can receive, interpret, and process QM.
- CV can collect the data requested in the QM.
- Based on the QM received, the CV can generate appropriate Response Message (RM) and send it to the RSU using short-range communication or directly to the TME using long-range communication.
- CV can receive, interpret, and process RSM to generate appropriate queue warning messages depending on the position of the vehicle relative to the BOQ.
- In-Vehicle Equipment in CV can provide the driver with customized queue warning with minimal distraction to the driver.
- If there is any V2V communication between CVs, it does not involve the transmission of queue-related information. Any such communication is limited to the transmission of BSMs outside of the functionality of this QA/QW design.

One of the project objectives is to take advantage of a new flexible messaging scheme defined by the Event-Driven Configurable Messaging (EDCM) concept. EDCM makes it possible to dynamically adjust the frequency and content of two-way data exchange between a CV and a TME depending on changes in traffic conditions. Figure 2 illustrates an example where the frequency of CV data changes depending on the rate of speed change of the CV. A sliding time window is used to check if the speed change is significant and sustained. The high-frequency (10 Hz) CV data is used by the TME to identify the locations of BOQ, FOQ, and additional significant slowdowns within the queue. The low-frequency data is sufficient to determine if a vehicle changes lane, exits the roadway, or stops.

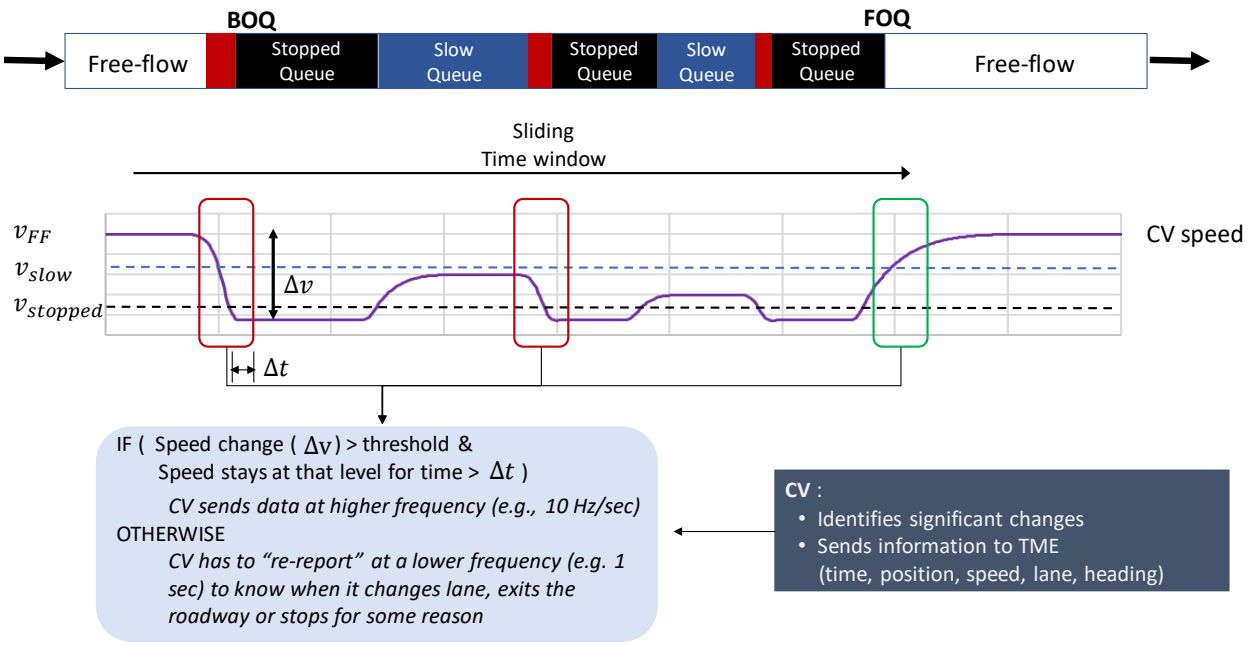


**Figure 2. Queue Detection Using CV Data of Different Frequencies.**

## 2.3. INFRASTRUCTURE TRAFFIC SENSORS

Traffic sensors in the V2I QA/QW system measure spot speeds and/or occupancies at multiple points. The sensor data is processed by a TME to detect queues and determine the appropriate response/warnings. The data collected by the sensors are averaged over pre-defined time intervals (e.g., 1-minute) and used by the TME to:

- detect the formation of queues,
- identify the location of the back of queue,
- estimate the speed of vehicles in the queue, and
- select appropriate queue warning messages.

Vehicle queues and significant slowdowns can be detected by comparing the time-averaged sensor data to thresholds defined for different queue conditions.

## 2.4. DYNAMIC MESSAGE SIGNS

Dynamic message signs (DMSs) are used for disseminating queue-warning messages for drivers approaching a vehicle queue. They are primarily intended for drivers of unequipped vehicles.

If possible, queue warning messages should also be provided on DMS upstream of potential diversion points (e.g., exit ramps or freeway junctions/interchanges). This gives drivers the option to divert to a less congested alternate route, if available.

## 2.5. ROADSIDE UNIT

The RSU provides the interface with two-way communication between the TME and the on-board unit (OBU) of the CV.

## 2.6. THIRD-PARTY TRAFFIC DATA PROVIDERS

Third-party traffic data providers offer crowdsourced probe vehicle data over a large portion of the roadway network. The data may include information on incidents and road construction, and segment travel times and speeds. For example, INRIX, HERE, and TomTom can provide agencies with access to their segment travel time and speed data feeds and some specific product features that can be useful for queue warning applications.

## 3. SYSTEM REQUIREMENTS FOR THE V2I QA/QW DATA AGGREGATION PROCESS

This section discusses high-level system requirements for the data aggregators used by the V2I QA/QW application. The QA/QW application obtains data from three primary sources: the traffic sensor system, connected vehicles, and third-party data providers. The primary function of the data aggregators is to obtain the data from these data sources and prepare it for use in the data fusion process. Table 1 provides the high-level system requirements for data aggregators associated with each data input into the V2I QA/QW application.

**Table 1. High-Level System Requirements for Data Aggregation.**

| Requirement Number | Requirement Description | User Need Traceability |
|---|---|---|
| **1.** | **DATA AGGREGATION** | |
| 1.1 | The V2I QA/QW system shall interface with the Traffic Sensor Subsystem of a TME to receive traffic monitoring information in each lane for each detector station. | QW-N8 |
| 1.1.1 | The traffic sensor system shall publish a timestamp associated traffic sensor data for each detection station. | |
| 1.1.1.1 | The traffic sensor system shall publish the average speed in each lane for each detector station. | |
| 1.1.1.2 | The traffic sensor system shall publish the measured volume in each lane for each detector station. | |
| 1.1.1.3 | The traffic sensor system shall publish the percent time occupancy in each lane for each detector station. | |
| 1.1.1.4 | The traffic sensor system shall publish the average time headway between vehicles. | |
| 1.1.2 | The traffic sensor systems shall publish the operational status of each traffic sensor. | |
| 1.1.3 | The traffic sensor system shall publish the geographic locations of center of each detection zone. | |
| 1.2 | The V2I QA/QW system may interface with radar-based traffic sensors capable of measuring vehicle trajectories. (Optional) | QW-N8 |
| 1.2.1 | The radar-based system shall provide measured vehicle movements on each link on a lane-by-lane basis. | |
| 1.2.2 | The radar-based system shall provide a trajectory of travel for each vehicle traveling in each lane. | |
| 1.2.3 | The vehicle trajectory shall provide the position and speed of each individual vehicle for the duration that the vehicle is traveling in the detection zone. | |
| 1.3 | The V2I QA/QW system shall interface with the Third-Party Data Provider Subsystem of a TME to receive congestion information at segment level and on a lane-by-lane basis, if available. | QW-N9 |

| Requirement Number | Requirement Description | User Need Traceability |
|---|---|---|
| 1.3.1 | The Third-Party Data Provider Subsystem shall provide any available queue information using Traffic Management Data Dictionary (TMDD) data formats. | |
| 1.3.2 | The Third-Party Data Provider Subsystem shall provide timestamp data. | |
| 1.3.3 | The Third-Party Data Provider Subsystem shall provide segment travel times. | |
| 1.3.4 | The Third-Party Data Provider Subsystem shall provide BOQ location if available. | |
| 1.4 | The V2I QA/QW system shall interface with an agency's Connected Vehicle Subsystem. | QW-N10 |
| 1.4.1 | The RSU shall be able to receive RMs from all equipped vehicles within its range. | |
| 1.4.2 | The RSU shall be able to receive RMs at a frequency of 10 Hz. | |
| 1.4.3 | The RSU shall be able to broadcast RSMs to all equipped vehicles within its range. | QW-N4 |
| 1.4.4. | The RSU shall be able to broadcast RSMs at a frequency of 1 Hz. | |
| 1.4.5 | The RSU shall be able to broadcast QM (including MAP Message) to all equipped vehicles within its range. | |
| 1.4.6 | The RSU shall broadcast QM at a frequency of 1 Hz. | |
| 1.5 | The V2I QA/QW system shall interface with an agency's Traveler Information System. | QW-N4 |
| 1.5.1 | The V2I QA/QW system shall interface with an agency's Dynamic Message signs. | |
| 1.5.2 | The V2I QA/QW system shall interface with other Traveler Information System devices. | |
| 1.6 | The V2I QA/QW shall interface with the agency's traffic sensor system data as defined by the TMDD requirement for providing roadway network data. | See TMDD V3.1 Requirement # 3.3.4 |
| 1.7 | The V2I QA/QW system shall interface with a configuration file that allows the operator to enter data elements needed. | |

## 4. SYSTEM REQUIREMENTS FOR THE DATA FUSION

This section discusses high-level system requirements for the data fusion process used in the V2I QA/QW application. The primary function of the data fusion application is to combine raw or processed data from the available sources. The data fusion process takes the input data and converts it to a common referencing system. Then it processes the data and assigns a confidence score to each data source based on its accuracy and timeliness. The information with the highest score is used for determining queue attributes. This process is continually repeated for all roadway segments covered by the V2I QA/QW system. Table 2 provides the high-level system requirements for the data fusion process.

**Table 2. High-Level System Requirements for the Data Fusion Process.**

| Requirement Number | Requirement Description | User Need Traceability |
|---|---|---|
| **2.** | **DATA FUSION** | |
| 2.1 | The V2I QA/QW system shall fuse queue data from multiple sources. | QW-N11 |
| 2.1.1 | The Data Fusion subsystem shall obtain data from agency's Traffic Sensor System. | |
| 2.1.2 | The Data Fusion subsystem shall obtain desired CV data. | |
| 2.1.3 | The Data Fusion subsystem shall obtain queue and/or travel-time data from Third-Party Data Providers. | |
| 2.2 | The V2I QA/QW system shall transform the data from multiple sources to a common reference. | QW-N11 |
| 2.2.1 | The Data Fusion subsystem shall transform data from all sources to a common geographical reference using the agency's Roadway Link Inventory. | |
| 2.2.2 | The Roadway Link inventory shall provide the name of the roadway network as assigned by the owner organization for each link. (TMDD V3.1 Req. #3.3.4.3.1.5.2.2) | |
| 2.2.3 | The Roadway Link inventory shall provide the name of the link as assigned by the owner organization for each link. (TMDD 3.3.4.3.1.5.2.3) | |
| 2.2.4 | The Roadway Link inventory shall provide all other name(s) of the link as assigned by the owner organization for each link. (TMDD 3.3.4.3.1.5.2.4) | |
| 2.2.5 | The Roadway Link inventory shall provide the primary route designator information for each link. (TMDD 3.3.4.3.1.5.2.5) | |
| 2.2.6 | The Roadway Link inventory shall provide other route designator information associated with the link. (TMDD 3.3.4.3.1.5.2.6) | |
| 2.2.7 | The Roadway Link inventory shall provide the linear reference location information for each link. The linear reference version information may also be included. (TMDD 3.3.4.3.1.5.2.3.7) | |

| Requirement Number | Requirement Description | User Need Traceability |
|---|---|---|
| 2.2.8 | The Roadway Link inventory shall provide the length of the link, in meters, for each link. (TMDD 3.3.4.3.1.5.2.8) | |
| 2.2.9 | The Roadway Link inventory shall provide posted speed limit along the link for each link. Unless indicated otherwise by the Speed Limit Units data element, the unit for posted speed limit is in kilometers per hour. (TMDD 3.3.4.3.1.5.2.10) | |
| 2.2.10 | The Roadway Link inventory shall provide the normal direction of travel on the link as part of the link inventory for each link. Supported values shall include northbound, northeast bound, eastbound, southeast bound, southbound, southwest bound, westbound, northwest bound, not directional, positive direction, negative direction, both directions, and any other. (Patterned after TMDD 3.3.5.1.2.1.2.10) | |
| 2.3 | The V2I QA/QW system shall merge the data from multiple sources to a common temporal reference. | QW-N11 |
| 2.3.1 | The V2I QA/QW system shall synchronize all time elements to UTC time. | |
| 2.3.2 | The V2I QA/QW system shall use GPS timestamp as the temporal reference. | |
| 2.4 | The V2I QA/QW system shall remove all PII (if any) from all data sources. | QW-N3 |
| 2.5 | The V2I QA/QW system shall integrate archived historical traffic data and queue information. | QW-N14 |

## 5. SYSTEM REQUIREMENTS FOR EVENT-DRIVEN CONFIGURABLE MESSAGING MANAGER

This section discusses high-level system requirements for the EDCM Manager used in the V2I QA/QW application. The primary function of the EDCM manager is to produce the Query Message (QM) for requesting different levels of data from connected vehicles based on the current travel conditions in the corridor. The EDCM Manager is also responsible for processing the Response Message (RM) produced by the connected vehicle. These requirements are consistent with the requirement developed by CAMP as specified in the *Event-Driven Configurable Messaging (EDCM): Queue Advisory and Queue Warning (QA/QW) System and In-Vehicle Application Requirement*[3] document.

Table 3 provides the high-level system requirements for the process associated with EDCM manager.

**Table 3. High-Level System Requirements for the EDCM Manager.**

| Requirement Number | Requirement Description | User Need Traceability |
|---|---|---|
| **3** | **EDCM MANAGER** | |
| 3.1 | The V2I QA/QW system shall have the ability to perform Event-Driven Configurable Messaging to equipped CVs. | QW-N6<br>QW-N7 |
| 3.2 | EDCM shall be capable of sending QMs to equipped CVs. | QW-N6 |
| 3.2.1 | QM shall specify the conditions under which equipped CVs shall provide an RM. | |
| 3.2.1.1 | QM shall specify the geo-fenced location of interest. | |
| 3.2.1.2 | QM shall specify the direction of travel. | |
| 3.2.1.3 | QM shall specify the sample time interval. | |
| 3.2.2 | QM shall specify the type of information that equipped vehicles shall provide in response. | |
| 3.2.2.1 | QM can request the vehicle to provide basic information. | |
| 3.2.2.2 | QM can request that the vehicle provide vehicle position and dynamic information. | |
| 3.2.2.3 | QM can request that the vehicle provide the status of its safety systems. | |
| 3.2.2.4 | QM can request the vehicle provide the status of vehicle-based systems. | |
| 3.2.3 | QM shall specify how equipped vehicles shall provide an RM. | |
| 3.2.3.1 | QM shall be capable of requesting instantaneous values from equipped vehicles. | |

[3] *Event-Driven Configurable Messaging (EDCM): Queue Advisory & Queue Warning (QA/QW) System and In-Vehicle Application Requirements.* Crash Avoidance Metric Partners, LLC (CAMP) Vehicle-to-Infrastructure (V2I) Consortium. June 2020 (Draft).

| Requirement Number | Requirement Description | User Need Traceability |
|---|---|---|
| 3.2.3.2 | QM shall be capable of requesting composite or averaged data from equipped vehicles. | |
| 3.2.3.2.1 | QM can specify that data be averaged over a given period of time. | |
| 3.2.3.2.2 | QM can specify that data be average over a defined distance traveled. | |
| 3.2.3.3 | QM shall be capable of requesting data from equipped vehicle based on specific criteria. | |
| 3.2.3.3.1 | QM can specify that data from equipped vehicles be provided based on certain vehicle status. | |
| 3.2.3.3.2 | QM can specify that data from equipped vehicles be updated at specified intervals. | |
| 3.2.3.3.3 | QM can specify that data from equipped vehicles be provided based on demand. | |
| 3.2.3.3.4 | QM can specify that data from equipped vehicles be provided based on pre-samples. | |
| 3.2.3.4 | QM shall be capable of requesting data from equipped vehicles located within a specified region of interest (geo-fenced). | |
| 3.3. | EDCM shall be capable of processing Response Messages (RM) from equipped connected vehicles. | QW-N7 |
| 3.3.1 | RM shall contain basic information about the vehicle. | |
| 3.3.1.1 | Basic information shall include the vehicle type. | |
| 3.3.1.2 | Basic information shall include a pseudo identifier for the vehicle. | |
| 3.3.2 | RM shall contain information about the vehicle position and dynamic information. | |
| 3.3.2.1 | The position and dynamic information shall include the coordinates (latitude/longitude) of the vehicle. | |
| 3.3.2.2 | The position and dynamic information shall include the current heading of the vehicle. | |
| 3.3.2.3 | The position and dynamic information shall include the instantaneous speed of the vehicle. | |
| 3.3.2.4 | The position and dynamic information shall include the current acceleration of the vehicle. | |
| 3.3.2.5 | The position and dynamic information shall include the current yaw of the vehicle. | |
| 3.3.2.6 | The position and dynamic information shall include the current steering wheel angle of the vehicles. | |
| 3.3.3 | RM shall contain information about the status of vehicle’s safety systems. | |
| 3.3.3.1 | The status of the vehicle’s safety systems shall include the activation of the brake. | |
| 3.3.3.2 | The status of the vehicle’s safety systems shall include the | |

| Requirement Number | Requirement Description | User Need Traceability |
|---|---|---|
| | activation of the traction control. | |
| 3.3.3.3 | The status of the vehicle's safety systems shall include the activation of the stability control. | |
| 3.3.4 | RM shall contain information about the status of other systems in the vehicle. | |
| 3.3.4.1 | The status of other vehicle systems shall include the status of the exterior lights. | |
| 3.3.4.2 | The status of other vehicle systems shall include current position of the wiper switch. | |
| 3.3.4.3 | The status of other vehicle systems shall include the external air temperature. | |
| 3.3.5. | RM shall provide information based on the aggregation interval specified in QM. | |
| 3.3.5.1 | The RM shall provide instantaneous values from equipped vehicles when requested in QM. | |
| 3.3.5.2 | RM shall provide composite or averaged data from equipped vehicles when requested in QM. | |
| 3.3.5.3 | RM shall report data from equipped vehicle based on the conditions specified in QM. | |
| 3.3.5.3.1 | RM shall report data from equipped vehicles based on vehicle status specified in QM. | |
| 3.3.5.3.2 | RM shall report the requested data from equipped vehicles at the intervals specified in QM. | |
| 3.3.5.3.3 | RM shall report the requested data from equipped vehicles on demand when specified in QM. | |
| 3.3.5.3.4 | RM shall report the requested data from equipped vehicles based on pre-samples specified in QM. | |
| 3.3.6 | RM shall provide the requested data from equipped vehicles when located within a specified region of interest (geo-fenced). | |
| 3.4 | EDCM shall use an eXtensible Markup Language (XML) messaging schema. | QW-N6<br>QW-N7 |

## 6. SYSTEM REQUIREMENTS FOR QUEUE ESTIMATION/ PREDICTION

This section discusses high-level system requirements for the Queue Estimation/Prediction process used in the V2I QA/QW application. The primary function of the Queue Estimator/Predictor is to detect the formation of queues in the traffic stream and compute attributes associated with each detected queue. Queue attributes include the location of FOQ, BOQ, and the speed at which the queue is propagating upstream (or downstream, depending on the situation). The Queue Estimator/Predictor is also responsible for determining the different regimes (slow moving or stopped) inside the queue. Figure 3 illustrates a simple queue detection logic with two speed thresholds defined as percentages of the free-flow speed. The speed threshold for determining the transition to slow traffic from free-flow speed and stopped traffic from slow traffic are to be user defined (e.g., 60% and 20%, respectively). The Queue Estimator/Predictor then forwards the attributes associated with each queue to the Message generator for use in producing alert and warning messages.

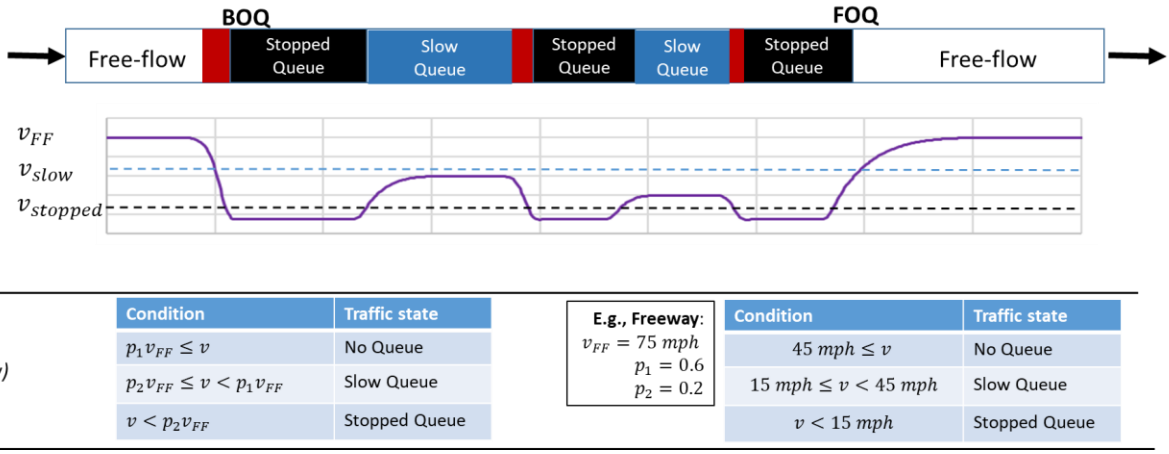


**Figure 3. Sensor-Based Queue Detection Logic.**

Table 4 provides high-level system requirements associated with the Queue Estimation/Prediction process.

**Table 4. High-Level System Requirements for the Queue Estimation/Prediction.**

| Requirement Number | Requirement Description | User Need Traceability |
|---|---|---|
| **4** | **QUEUE ESTIMATION/PREDICTION** | |
| 4.1 | The V2I QA/QW system shall be able to detect when a queue forms in each direction of travel. | QW-N5, QW-N12 |
| 4.1.1 | The V2I QA/QW system shall be able to detect when a queue forms on a lane-by-lane basis. | |
| 4.2 | The V2I QA/QW system shall be able to determine the lane(s) which are operating in queued state. | QW-N5, QW-N12 |
| 4.2.1 | The V2I QA/QW system shall be able to determine when travel in the lane has reached a "slow" queue state. | |
| 4.2.2 | The V2I QA/QW system shall have a user-defined threshold for each lane defining the transition between a "slow" queue state and a "stopped" queue state. | |
| 4.2.3 | The V2I QA/QW system shall have a user-defined threshold for each lane defining the transition from a free-flow state to a "slow" state. | |
| 4.3 | The V2I QA/QW system shall determine the geographic location of the queue. | QW-N5, QW-N12 |
| 4.3.1 | The V2I QA/QW system shall be able to determine the geographic coordinates of the location of the FOQ in each lane. | |
| 4.3.2 | The V2I QA/QW system shall be able to determine the geographic coordinates of the location of the BOQ in each lane. | |
| 4.4 | The V2I QA/QW system shall be able to determine the length of the queue in each lane. | QW-N5, QW-N12 |
| 4.5 | The V2I QA/QW system shall be able to determine the average speed of vehicles within the queue in each lane. | QW-N5, QW-N12 |
| 4.6 | The V2I QA/QW system shall estimate the expected delay experienced by travelers in the queue. | QW-N5, QW-N12 |
| 4.7 | The V2I QA/QW system shall be able to estimate queue propagation/dissipation. | QW-N5, QW-N12 |
| 4.7.1 | The V2I QA/QW system shall be able to determine or predict the speed at which the BOQ propagates/dissipates in each lane. | |
| 4.7.2 | The V2I QA/QW system shall be able to determine or predict the speed at which the FOQ propagates/dissipates in each lane. | |
| 4.8 | The V2I QA/QW system shall be able to detect when a queue dissipates (i.e., when travel conditions return to free flow). | QW-N5, QW-N12 |

## 7. SYSTEM REQUIREMENTS FOR V2I QA/QW MESSAGE GENERATION

The primary purpose of the V2I QA/QW system is to generate alert and warning messages to warn drivers approaching the back of the queue. The V2I QA/QW system has to be able to support the dissemination of queue information via multiple methods, including infrastructure-based traveler information system such as a DMS, RSM-based customized in-vehicle queue warning in each CV, and third-party data providers.

DMSs are used for disseminating queue-warning messages for drivers approaching a vehicle queue. They are primarily intended for drivers of unequipped vehicles, but will also be seen by drivers of CV. The locations and number of DMSs included in a V2I QA/QW system should be determined based on the longest expected queue lengths. At least one warning message sign should be deployed upstream of the longest queue to ensure that drivers are protected at all times. If DMSs are not available, portable changeable message signs (PCMS) should be used. Warning message signs should be deployed and positioned in such way that they are clearly visible for all drivers traveling in any of the lanes. If possible, queue warning messages should also be provided upstream of potential diversion points (e.g., exit ramps or freeway junctions/interchanges). This gives drivers the option to divert to a less congested alternate route, if available.

The CV subsystem must also generate appropriate advisory and warning messages depending on the proximity of the CV to the location of BOQ. The process for generating alert and warning messages by the in-vehicle QA/QW application is described in *Event-Driven Configurable Messaging (EDCM): Queue Advisory and Queue Warning (QA/QW) System and In-Vehicle Application Requirement*.[4] The in-vehicle alert automatically determines the type of message (an "Alert" or a "Warning" message) depending on a CV's estimated travel time (distance) to BOQ. 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.) and shockwave speed given 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 (at lane- or road-level, as available). Figure 4 illustrates the "Inform" and "Warn" zone concepts. In this figure, the start of the "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.

The system also needs to support the dissemination of queue information to other ITS information providers and third-party data providers. It is envisioned that a TME would communicate queue information via center-to-center communications protocols, using *Traffic Management Data Dictionary (TMDD)* messaging.

[4] *Event-Driven Configurable Messaging (EDCM): Queue Advisory & Queue Warning (QA/QW) System and In-Vehicle Application Requirements.* Crash Avoidance Metric Partners, LLC (CAMP) Vehicle-to-Infrastructure (V2I) Consortium. June 2020 (Draft).

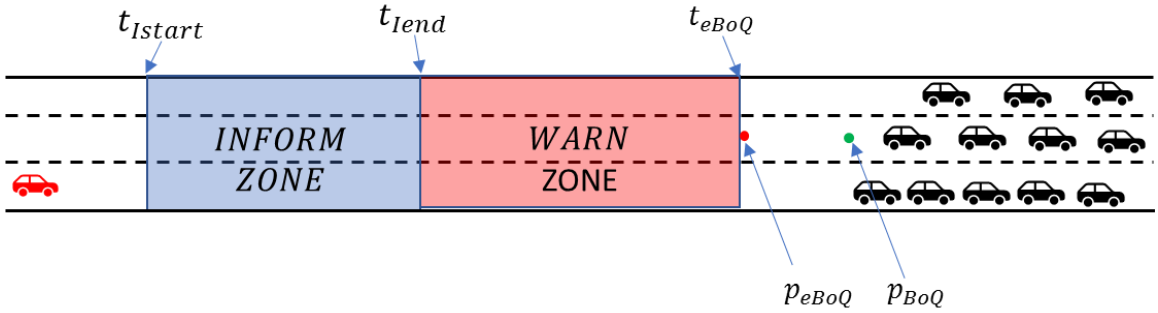


**Figure 4: Estimation for "Inform" and "Warn" Zones.**

Table 5 provides the high-level system requirements for process associated with generating the different types of queue alert and warning information.

**Table 5. High-Level System Requirements for Generating Queue Alert and Warning Messages.**

| Requirement Number | Requirement Description | User Need Traceability |
|---|---|---|
| **5** | **MESSAGE GENERATION** | |
| 5.1 | The V2I QA/QW system shall disseminate queue information to vehicles through multiple sources of information dissemination technology. | QW-N15 |
| 5.1.1 | The V2I QA/QW system shall produce a queue warning message when traffic is in the “slow” state. | |
| 5.1.2 | The V2I QA/QW system shall produce a queue alert message when traffic is in the “stopped” state. | |
| 5.1.3 | The V2I QA/QW system shall remove warning and alert messages when traffic is in the “free-flow” state. | |
| 5.1.4 | The V2I QA/QW system shall automatically select the appropriate information dissemination devices (e.g., DMS or PCMS) based on the current location of the back of the queue. | |
| 5.2 | The V2I QA/QW system shall generate appropriate messages for displaying on agency’s DMSs. | QW-N1, QW-N13 |
| 5.2.1 | The V2I QA/QW system shall identify to a TME operator the appropriate DMSs associated with each queue detected. | |
| 5.2.2 | The V2I QA/QW system shall recommend to a TME operator the appropriate message to be displayed on each identified DMS with each queue detected. | |
| 5.2.2.1 | For DMSs located upstream of the back of queue, the V2I QA/QW system shall generate a message indicating the travel distance (in one-tenth of a mile increment) to the back of the queue. | |
| 5.2.2.2 | For DMSs located within the queue region, the V2I QA/QW system shall be able to provide messages indicating the expected time (or delay) to reach the front of the queue. | |

| Requirement Number | Requirement Description | User Need Traceability |
|---|---|---|
| 5.2.2.3 | For DMSs located within the queue region, the V2I QA/QW system shall be able to provide messages indicating the remaining travel distance to the front of the queue. | |
| 5.2.3 | The V2I QA/QW system shall be able to alter the update interval of the queue warning messages based on the speed of BOQ propagation upstream (shockwave speed). | |
| 5.3 | The V2I QA/QW system shall send information to connected vehicle for producing queue alerts and warnings. | QW-N4 |
| 5.3.1 | The V2I QA/QW system shall automatically generate a Road Safety Message (RSM) containing the queue information in the Queue Container. | |
| 5.3.1.1 | The queue container shall include a *Road Surface Condition Data Element* describing the current road condition (e.g. Dry, wet, snow). (Optional) | |
| 5.3.1.2 | The Queue Container shall include a *Queue Status List* data element which lists the queue status for each applicable lane. | |
| 5.3.1.3 | The Queue Container shall include an *Associated Lane* data element which identifies the lane for which the information in *Queue Status* is relevant. | |
| 5.3.1.4 | The Queue Container shall include a Q*ueue Ahead Warning* data element indicates the presence or absence of a queue ahead. | |
| 5.3.1.5 | The Queue Container shall include a *BOQ Position* data element providing the estimated position of the last vehicle in the queue. | |
| 5.3.1.6 | The Queue Container shall include a *BOQ Position Update Time* data element providing the date and time at which the BOQ position was last updated. (Optional) | |
| 5.3.1.7 | The Queue Container shall include a *BOQ Shockwave Speed* data element providing the rate at which the BOQ is moving. A negative value indicates the queue is growing toward the upstream traffic. | |
| 5.3.1.8 | The Queue Container shall include a *FOQ Position* data element providing the estimated position of the front bumper of the first vehicle in the queue. | |
| 5.3.1.9 | The Queue Container shall include a *FOQ Shockwave Speed* data element providing the rate at which the FOQ is moving. The rate of zero indicates the FOQ is stationary. (Optional) | |
| 5.3.1.10 | The Queue Container shall include a *Queue Confidence* data element providing the average confidence (in %) of the estimation, queue speed, FOQ and BOQ position, and shockwave speeds. | |
| 5.3.2 | The V2I QA/QW system shall identify to a TME operator the appropriate RSUs associated with each queue detected. | |
| 5.3.3 | The V2I QA/QW system shall update the RSM based on current queue information. | |

| Requirement Number | Requirement Description | User Need Traceability |
|---|---|---|
| 5.4 | The V2I QA/QW System should automatically update the appropriate information dissemination devices as the queue information is updated. | QW-N2 |
| 5.4.1 | The V2I QA/QW System shall automatically update the messages displayed on dynamic message signs as the queue information is updated. | |
| 5.4.2 | The V2I QA/QW System shall automatically update the RSM message as the queue information is updated. | |
| 5.5 | The V2I QA/QW system shall share queue information with other ITS subsystems using a TMDD message structure. | QW-N17 |
| 5.6 | The V2I QA/QW system shall be able to share queue information with third-party data providers. | QW-N18 |

## 8. SYSTEM REQUIREMENTS FOR GENERATING V2I QA/QW SYSTEM PERFORMANCE MEASURES

The V2I QA/QW system needs to support the automatic generation of system performance measures. System performance measures allow agencies to monitor and assess both the functionality and the effectiveness of the V2I QA/QW applications. This module needs to archive the information generated by the system so that it can be used to assess its accuracy, reliability, timeliness, and effectiveness. Table 6 provides the high-level system requirements for processes associated with generating and retaining different system performance measures.

**Table 6 High-Level System Requirements for Generating System Performance Measures.**

| Requirement Number | Requirement Description | User Need Traceability |
|---|---|---|
| **6.** | **Performance Measurement** | |
| 6.1 | The V2I QA/QW system shall archive traffic and vehicle data collected from multiple sources for post-event processing. | QW-N16 |
| 6.1.1 | The V2I QA/QW system shall archive the data collected from the connected vehicles used to estimate queues. | |
| 6.1.1.1 | The V2I QA/QW system shall archive the coordinates (latitude and longitude) of the position of the connected vehicles within a defined geo-fenced area used in the queue estimation process. | |
| 6.1.1.2 | The V2I QA/QW system shall archive the instantaneous speed of the connected vehicles within a defined geo-fenced area used in the queue estimation process. | |
| 6.1.1.3 | The V2I QA/QW system shall archive the heading of the connected vehicles within a defined geo-fenced area used in the queue estimation process. | |
| 6.1.1.4 | The V2I QA/QW system shall archive the connected vehicle data for each user-defined geo-fenced area. | |
| 6.1.2 | The V2I QA/QW system shall archive the data collected from all traffic sensors used by the system. | |
| 6.1.2.1 | The V2I QA/QW system shall archive the time-averaged speed from all traffic sensors used to estimate queues. | |
| 6.1.2.2 | The V2I QA/QW system shall archive the percent time occupancy of all traffic sensors used to estimate queues. | |
| 6.1.2.3 | The V2I QA/QW system shall archive the volume measured by all traffic sensors used to estimate queues. | |
| 6.1.3 | The V2I QA/QW system shall archive all data from third-party providers used to estimate queues. | |
| 6.1.4 | The V2I QA/QW system shall archive all infrastructure-based vehicle trajectory data used. | |
| 6.1.5 | The V2I QA/QW system shall archive all traffic and vehicle data on a per lane basis. | |

| | | |
|---|---|---|
| 6.1.6 | The V2I QA/QW system shall archive all traffic and vehicle data at a user defined interval (e.g., 20-seconds) | |
| 6.1.7 | The V2I QA/QW system shall provide a timestamp associated with each archived entry. | |
| 6.2 | The V2I QA/QW system shall archive all the queue estimation attributes computed for each lane at a user-defined interval. | QW-N16 |
| 6.2.1 | The V2I QA/QW system shall archive the coordinates (latitude/longitude) of the FOQ. | |
| 6.2.2 | The V2I QA/QW system shall archive the coordinates (latitude/longitude) of the BOQ. | |
| 6.2.3 | The V2I QA/QW system shall archive the length of the queue. | |
| 6.2.4 | The V2I QA/QW system shall archive the delay in queue. | |
| 6.2.5 | The V2I QA/QW system shall provide a timestamp associated with each archived entry. | |
| 6.3 | The V2I QA/QW system shall archive all queue warning messages and RSM generated by the TME | QW-N16 |
| 6.3.1 | The V2I QA/QW system shall archive all queue warning messages displayed on all DMSs for each geo-fenced area. | |
| 6.3.2 | The V2I QA/QW system shall archive all RSM broadcasted to CVs through each RSU for each geo-fenced area. | |
| 6.3.3 | The V2I QA/QW system shall provide a timestamp associated with each archived entry. | |