Connected Traffic Control System (CTCS): Research Planning and Concept Development

Task 6: Concept of Operations

Queue Length Detection

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Introduction

Emerging connected vehicle (CV) environments have the potential to enable enhanced detection and to correct estimation of a vehicle queue length at an urban intersection or freeway on-ramp. This advance in detection data beyond the existing detection systems is anticipated to be an important component of both effective traffic management and efficient operation of individual vehicles. Webster's dictionary defines a queue as "a waiting line especially of persons or vehicles." For the purposes of this report, queues are considered to be vehicles waiting in line on an arterial roadway or metered on-ramp. Queues create shockwaves to traffic flow that constrain free-flow movement on the facility. Knowledge of queue lengths is needed to pinpoint intersection bottlenecks and determine their cause—excessive demand or poor traffic control. Information about vehicle queues is necessary for signal control (to minimize cycle failures and traffic spillbacks to upstream intersections) and for ramp metering (to minimize traffic spillbacks into arterials or other freeways). For individual vehicles, accurate queue information enables optimization of energy consumption.

However, vehicle queue estimation can be difficult, especially in the congested environment when traffic spillbacks occur. Challenges arise from traffic spillbacks to upstream junctions, when it becomes unclear where one queue ends and the other begins. There are also challenges resulting from the insufficient number of CVs and from multiple queues forming on a single approach (e.g., when part of the traffic is queued up to make a left turn, and the other part of the traffic waits for a straight movement). Finally, queue estimation is made difficult from errors in vehicle localization.

Those familiar with this topic are aware that a significant amount of research has already been devoted to queue length estimation and queue spillback detection. Looking to the future, vehicle-to-everything (V2X) communications is a widely considered technology for application to queue estimation. The technology readiness level (TRL) for this technology has been estimated by the project team to be at the level of lab demonstration (TRL 5), and there is a need for a working prototype in the complex operational domain.

Building on this past work, the vision is to be able to provide queue length data such that it can be used to optimize traffic signal control along a corridor as well as to be able to provide data that enables applications within highly automated vehicles. Those capabilities—which we will refer to as a Queue Length Detection (QLD) systems, QLD data, and QLD processors—are referenced throughout this report.

- QLD systems imply that several components of the system are working together.
- QLD data refers more specifically to the QLD system outputs.
- QLD processors would be responsible for manipulating and processing QLD-related data.

This Concept of Operations (ConOps) works from the assumption that the data produced may still be considered an estimation, not detection, until penetration rates of CVs reach near 100 percent. That being said, stakeholders who are familiar with algorithms that could use this data have reported that there is a lot to learn even when penetration levels are low, and would encourage deployers to continue advancing research in this area because limited information is better than the estimates and assumptions that are being made today.

This ConOps has its origins in the work plan developed for the Connected Traffic Control System (CTCS) project to develop a research plan for the Connected Vehicle Pooled Fund Study (CV PFS) that is focused on the needs of traffic signal systems along arterial corridors and to prioritize research areas within a research road map, and then to develop the ConOps of high-priority research areas.

The project team selected Queue Length Detection as best suited for ConOps development for three reasons. First, this research area ranked 1st in terms of priority during the April stakeholder meeting in Ann Arbor. A detailed description of the ranking process as it relates to QLD can be found in Application Scenario 6 in Appendix B of Task 4. Second, when the project team completed the literature review task and review of current activities, the TRL associated with this proposed research area was deemed to be a TRL 5. Under normal circumstances a TRL 5 would not warrant a ConOps, but because the work related to Queue Length Detection has primarily been focused on freeway applications, and because stakeholder interest is focused on signalized arterials, the TRL must be calibrated down to TRL 3, justifying the need for the ConOps. Finally, for Queue Length Detection, Task 5, Section 3 shows the next step is a design/simulation activity and developing a high-level ConOps prior to this type of activity lays a good foundation for future work. An overview of previous and on-going QLD research can be found in Task 5, Section 2.2.1. Recommended research activities for QLD are described in Task 5, Section 4.1.1.

1.0 Scope

1.1 Identification

This ConOps describes the research that was done and more specifically includes a set of scenarios where a range of operating conditions make it clear how the concept would operate.

This ConOps does the following:

- Ensures stakeholder needs and expectations are captured early.
- Identifies existing operational environment and roles.
- Identifies how the concept could enhance existing situations.
- Identifies operational requirements; begin the process of linking needs with specific requirements.
- Provides contextual framework needed to support future prototyping efforts.

1.2 Document Overview

This ConOps adheres to industry accepted systems engineering practices and was developed in a non-technical manner so that it can be easily understood by anyone regardless of background or familiarity with previous efforts. It defines the characteristics or features of a proposed system from the user's viewpoint, which includes the infrastructure owner/operator but also includes road users and other pertinent groups. A stakeholder group provided input in the development of the concept and established a vision for the concept in support of future prototyping efforts. System elements are specifically itemized, including non-human users such as the traffic signal control system. Development of a ConOps is a critical early step in the systems engineering process, because it forms the foundation for future research and development activities.

This ConOps is organized into the following primary sections:

- Referenced Documents (Section 2)
- Current System (Section 3)
- Justification for and Nature of Changes (Section 4)
- Concept for the Proposed System (Section 5)
- Operational Scenarios (Section 6)
- Summary of Impacts (Section 7)
- Analysis of the Proposed Concept (Section 8)

1.3 System Overview

This document is the starting point to developing how a QLD system would operate and forms the basis for the ultimate development of detailed research project needs and more detailed system requirements.

This ConOps was developed as part of a CV PFS project to develop a research roadmap for CTCS); thus, the CV PFS members as part of CTCS project are the intended audience for this document. However, this ConOps may be used by other researchers or practitioners interested in establishing a system to calculate QLD data.

The QLD System would provide dynamic information to estimate current queue length based on available data, estimate predicted queue length, and provide estimated current and predicted queue length to external systems in near real time. The fidelity of the required data, latency maximums, and how often messages should be shared should be explored through future research. Best practices in providing “real-time” information are assumed to be followed.

As shown in Figure 1, the system of interest, which includes the QLD system, interfaces with four key elements: 1) roadside equipment, 2) CVs, 3) system operator, and 4) data fusion companies. The focal elements of the system diagram are shown with a bold black border in the diagram: in-vehicle equipment, CV roadside equipment, and the QLD system. Section 5.3, “Description of Proposed System Details” describes each system element.

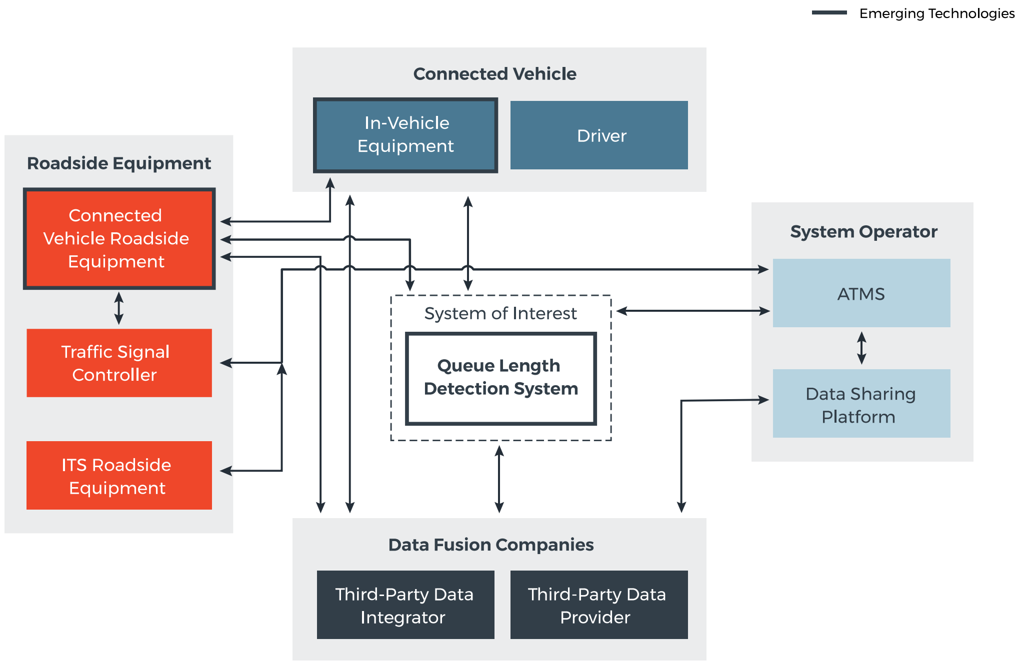

Figure 1: Queue Length Detection System Diagram

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3.0 Current System

3.1 Background, Objectives, and Scope

Currently, a system that detects and estimates queues in real time and makes the information broadly available to traffic management applications or to vehicle drivers does not exist. Queues have historically been detected at fixed locations using loop, video, or radar detectors and the information embedded in traffic control algorithms, such as UTCS, SCOOT, and others. The advent of CVs, where equipped vehicles broadcast vehicle information (e.g., basic safety messages) at 10 Hz, provides the opportunity to detect and estimate the characteristics of queues in critical traffic control areas such as at intersections, freeway ramps, and roadway sections where congestion occurs.

These concepts are now expected to span beyond single signalized intersections to consider the entire signalized corridor and also allow for the use of data collected through two-way communications with CVs through the infrastructure’s Road Safety Message (RSM) and with infrastructure-based traffic management and control systems, including Signal Phase and Timing (SPaT) and MAP messages that are typically shared in CV environments.

3.2 Operational Polices and Constraints

System Architecture
The existing system should be captured in existing ITS architecture documentation. ITS architecture will likely differ from region to region. This documentation provides a framework for the integration and interoperability of the proposed QLD system with existing ITS systems.

Vehicle Operation Laws and Regulations
The movement of drivers, bicyclists, and pedestrians are governed through laws and regulations that are set at the state and local levels. All roadway users operating in the environment in which the queue detection system is deployed are expected to behave in a manner such that they adhere to applicable laws and regulations.

3.3 Description of the Current System

Currently, queue length is estimated at signalized intersections utilizing loop detectors and through ITS solutions such as video detection and radar. Simple traffic control concepts, such as third-car detection, integrate queue information into signal timing. More complex approaches, such as adaptive traffic signal control (e.g., SCOOT, OPAC, and RHODES), utilize queue estimation as an integral part of the adaptive signal timing. SCOOT utilizes departure detectors at the upstream intersections to generate link profiles that accumulate into queues during red intervals. OPAC utilizes approach detectors to predict the arrival at the stop bar and adds vehicles to the queue as they arrive. RHODES utilizes peer-to-peer communications from upstream intersections to send departure information to the downstream intersection and accumulates the predicted arrivals into queues when the signal is red or when the queue is not empty. Liu, et. al., (2009) combine stop bar and advanced detector information, using traffic flow theory to estimate queue length, accumulation rate, and discharge rate in congested conditions at signalized intersections.

Vehicle-to-everything (V2X) communication is one of the technologies whose application to queue estimation is widely considered. As determined in Task 4 of the CTCS project, the readiness level for queue detection with this technology is at the level of lab demonstration. A working prototype is needed in the complex operational domain, recognizing that market penetration of V2X vehicles is a challenge to the success of more than a laboratory experiment.

Vehicle queue estimation can be difficult, especially in the congested environment when traffic spillbacks occur. Challenges arise from traffic spillbacks to upstream junctions, when it becomes unclear where one queue ends and the other begins. Challenges also result from the insufficient number of CVs and from multiple queues forming on a single approach (e.g., when part of the traffic is queued up to make a left turn, and the other part of the traffic waits for a straight movement). Finally, queue estimation is made difficult from errors in vehicle localization.

Recent research that led up to this effort includes work done through the Applications for the Environment: Real-Time Information Synthesis (AERIS) program, which focused on moving one vehicle through an intersection in an assumed pre-timed signal in an environmentally friendly manner to minimize fuel use. The application provided a speed recommendation to a single vehicle as it was approaching a signalized intersection. This application was integrated into the vehicle controls to automate the vehicle by controlling its acceleration as it approached the intersection.

Related research was conducted toward moving a string (platoon) of vehicles through a corridor of signalized intersections as part of the Traffic Optimization for Signalized Corridors (TOSCo) project, which is led by CAMP (https://www.campllc.org/traffic-optimization-for-signalized-corridors-tosco-phase-2-build-and-test/). Instead of just one intersection, a corridor of coordinated/actuated signals was evaluated. The objective of TOSCo is to get strings (platoons) of vehicles through the intersection within the time window that the vehicle has to make the green. Seven modes of operation have been identified that the vehicles follow. Currently, the TOSCo project does not assume the string has the ability to change, or request a change in, the timing of the signal along the corridor, but this capability has been identified as future research to determine the feasibility of integrating traffic signal priority, preemption, or extension treatment for a string of vehicles.

The Multi-modal Intelligent Traffic Signal System (MMITSS) project utilizes CV data to estimate queue information in the traffic signal control algorithms as part of the Intelligent Traffic Signal Control (I-SIG), Emergency Vehicle Priority (EVP), Transit Signal Priority (TSP), and Freight Signal Priority (FSP) applications. Queue length is used to determine how long it would take to clear a queue when a priority eligible vehicle is approaching intersections, to determine phase duration when allocating green time to the different movements, and to estimate performance measures, including delay and travel time. The Signal Phase and Timing (SPaT) message as defined in the SAE J2735:2016 standard includes a field for the current queue length.

3.4 Modes of Operation

Normal Operating Conditions

Normal operating conditions indicate the system is functioning as expected—generating outputs as intended and not generating outputs when unnecessary. Drivers would be expected to adhere to existing laws and regulations associated with traffic control devices (e.g., traffic signals, signage, and lane markings) with the added benefit of information and notifications that complement these laws and regulations.

Detection Equipment Calibration Issue

The primary means of queue detection in the existing system are loop and video detectors. Both of these systems rely on calibration for the system to properly identify a passing vehicle and detect its speed. Furthermore, video detection systems are prone to inaccuracies due to sunlight glare off vehicles, image stability issues due to wind (if pole mounted), and low-visibility conditions (e.g., rain, snow, or fog). Improperly detected or undetected queues may result in the failure of other systems to operate properly (i.e., implementing a strategy when none is warranted, or not implementing a strategy when it is warranted), because the other systems rely on accurate queue detection data.

Offline or Non-Functioning Detection Equipment.
A number of conditions may cause system failure, which may include but are not limited to loss of power or connectivity, or no longer functioning detection equipment. These failures do not allow queues to be detected at all, which do not allow systems that rely on queue detection data to provide any benefit.

3.5 User Classes and Other Involved Personnel

Vehicle Operator
Vehicle operators are the primary users affected by existing systems that rely on queue detection. Within the context of the existing system, all vehicle operators drive vehicles that are detected by roadside vehicle detection equipment. There are unequipped vehicles, and there may be vehicles capable of wireless communications, but the existing system detects all of these vehicles in the same manner, and provides outputs to each vehicle operator in the same manner. It is important to note that the proposed system would interact differently between vehicles with and without wireless communications equipment.

Traffic Management Staff
Current queue detection systems are operated and maintained by traffic management staff, who are also typically responsible for operations and maintenance of other ITS equipment and systems.

Advanced Traffic Management System (ATMS)
ATMS is commonly used by traffic operations personnel to monitor traffic conditions and control infrastructure systems. Different queue detection systems in different jurisdictions may operate differently depending on how they are designed to operate. Some systems are able to utilize information regarding a detected queue to automatically trigger the implementation of a queue management strategy, while other systems may simply provide an alert to traffic management staff, who must then decide on the best course of action and manually implement an available strategy. In either case, it is the responsibility of the traffic management staff to continuously monitor system operations, adjust the detection equipment calibration when needed, perform maintenance on malfunctioning equipment, and restore connectivity should system communications be interrupted.

3.6 Support Environment

The system should include software tools for verification and validation of operations and for system diagnosis and troubleshooting. Verification and validation can be accomplished by integrating ITS video feeds with queue visualization software. System diagnosis and troubleshooting can utilize test vehicles, network packet sniffers (e.g., Wireshark), and other operating system utilities.

4.0 Justification for and Nature of Changes

4.1 Justification of Changes

CV environments require a significant exchange of data between actors in order to operate efficiently. Accuracy in detecting or estimating vehicle queue length at an urban intersection or a freeway on-ramp is an important data component needed to effectively manage traffic and to efficiently operate individual vehicles.

This type of data is typically collected at intersection through ITS sensors, which are costly to install, operate, and maintain. Additionally, ITS sensors can collect data only where installed and calibrated at a single point or small defined area that is visible to a video detection system.

A body of research on QLD in a CV environment is building; however, most research to date has focused on freeway applications rather than on arterials and on ramp meter locations.

Crash statistics from the National Highway Traffic Safety Administration show an overall increase of 20 percent in fatal rear-end crashes on roadways between 2008 and 2018, and many of these are happening on arterial roadways.

4.1.1 Stakeholder Engagement

To inform the development of this ConOps, feedback was collected from a diverse group of stakeholders. The group included industry organizations, automakers, technology providers, ITS device and traffic signal control vendors, academic researchers, and infrastructure owner/operators. The primary group of stakeholders engaged on this project were those serving on the project panel. Additional stakeholder engagement was sought out specifically to support the development of the ConOps. To achieve this additional engagement interview requests were sent to eight stakeholders, six responses were received, and five interviews were conducted. Appendix B provides additional details regarding these interviews. This diverse group of stakeholders may not reflect input from arterial operators specifically; further outreach to that specific stakeholder group (and any other specific groups) would be beneficial in follow-up work. Recurring themes and unique ideas uncovered in the interviews are detailed in the following subsections.

Recurring Themes from Stakeholder Interviews

The stakeholders interviewed made it clear that lane-specific detailed queue information would help to address various needs related to their individual perspectives, such as: to assist with advancing other research initiatives; to improve safety; or to enable improved signal timing along corridors. They also reported that at this time the level of accuracy that would be required to enable applications using QLD data is unclear because the data is generally not available, which results in a large number of assumptions and estimates of this type of data to be made by researchers and deployers alike in related research or piloting activities along arterial corridors or at ramp meter locations. The stakeholders were open with sharing their thoughts on how queue data should be parsed, including the following:

- Back of the queue location
- Indication as to if the queue length is increasing or decreasing

- Queue movement, such as if the queue stopped or slowly moving
- Classification of vehicles
- Acceleration rates of other vehicles
- Presence of pedestrians

The stakeholders also generally agreed that detailed signal information must also be provided, including the following:

- Arrival rates
- Known traffic signal system patterns
- Initial length of queue at the start of the cycle
- Current status of the signal

One stakeholder explained that the queue increase rate and queue spillback information were especially critical factors that were extremely difficult to estimate with existing data.

A common shared opinion was that data would be expected to be processed at the edge—meaning that the data would not go back to the system operator or central system to process the data—and it must be calculated in real-time at the intersection and then can be shared with the system operator.

Stakeholder consensus was that benefits would be realized even with a small percentage (5 percent to 10 percent) of CVs able to help with QLD calculations.

If/when all vehicles become connected, then operational strategies at intersections would change drastically to become slot-based and more like air traffic control. While not stated explicitly, this is clearly the end goal for those deeply involved with these efforts due to the potential benefits associated with machine-to-machine applications.

Arterial streets are designed to accommodate queues and unmet demand due to signal timing. Intersections are designed to plan for queues and provide storage for queues. Generally, queues are not so bad. Critical information (such as if the queue is exceeding the planned storage areas) is important.

- A lot can be done with current ITS detection systems.
- QLD has a strong linkage with travel time information.
- QLD must optimize the entire corridor / CV environment, not just one signal.

Unique Ideas from Stakeholder Interviews

Merging QLD with some third-party data may be difficult because the time scale, frequency, and spatial measurements are so different. For example, Inrix travel times are tied to Traffic Message Channels, which makes the data easier to measure and use. How would QLD translate into a Traffic Message Channel system at a large scale? Would it be compatible with a system that has segments much larger than the desired queue length resolution?

NoTraffic—a turnkey traffic management platform powered by vehicle-to-infrastructure communication and real-time optimization of signalized intersections—reports being able to produce QLD information through its current system of separately deployed monitoring equipment and would not likely use additional info if it were available.

Operational goals for corridors are emerging to move as many people (instead of vehicles) through a corridor as possible; therefore, vehicles with more passengers would have priority.

QLD relates strongly to many projects that Contra Costa Transportation Authority already has underway. Traffic signal timing information is being integrated into private vehicles as well as shared with Automated Vehicle (AV) shuttles. A project is also underway that would provide more green time to transit vehicles with more passengers based on data integration with transit CAD/AVL systems. GoMentum Station has the ability to test the concept with six different traffic signal controllers and Dedicated Short Range Communications (DSRC) vendors. The Innovate680 project would require advanced ramp metering to accommodate bus on shoulder operations that would need to hold the ramp meter from servicing other vehicles while transit vehicles pass, while optimizing the system as a whole.

MMITSS Phase I in the Anthem Test Bed used real-time QLD from CVs with the roadside unit (RSU) receiving basic safety messages (BSM) and doing the processing on the RSU. Unfortunately, not enough vehicles in the test bed could verify the data through MMITSS.

Validating QLD results is challenging, but estimating computations and getting the values is straightforward. Video can be used, but it is costly to implement at all locations and spend the time doing the analysis.

The stakeholder inputs along with the guidance of the stakeholders on the CTCS project panel have helped to guide the development of this ConOps.

4.2 Description of Desired Changes

QLD would be enabled through CV technologies and through vehicle-to-infrastructure and vehicle-to-vehicle communications. This technology allows vehicles within the queue event to automatically broadcast their queued status information (e.g., rapid deceleration, disabled status, location) to nearby upstream vehicles and to roadside equipment and traffic management centers or system operators. CVs have the capability to provide the data needed to identify where the end of queues are located and share that information to other users, including system operators, vehicle manufacturers, and other roadway users.

QLD data would enable various CAV applications to become more reliable and effective. For example, queue warnings broadcast from infrastructure owner/operators to vehicles in order to minimize or prevent rear-end or other secondary collisions. QLD would be designed to engage well in advance of any potential crash situation, providing messages and information to the driver to minimize the likelihood of the driver needing to take crash avoidance or mitigation actions later. Another example would be how QLD data would interface with strings of vehicles, such as those being modeled and tested in the TOSCo project, in order to provide accurate data that would inform where the string should plan to slow or stop as it approaches an intersection or queue. Data fusion would be required from various partners, including public and private sources that vary by region.

QLD may be considered safety critical data that would enable safety applications, which makes security an important element of the QLD design. Inaccurate or unreliable information would cause too much demand on vehicle or roadway sensors; it could also cause the transportation system operations to diminish when the data is not available.

User Needs

Feedback from the stakeholder engagement and research culminated in a list of user needs associated with the detection and response to the formation of queues on an arterial roadway network. Table 1 presents these user needs grouped by each user class. These user needs are expected to be supported through the deployment of ITS technology, which may include the use of CV communications.

Table 1: User Needs

IDENTIFICATION	TITLE	DESCRIPTION	RATIONALE
Vehicle Operator			
QLD-UN1.01-V01	Minimize Delay	A vehicle operator needs knowledge of queues in the network to traverse the roadway in an efficient manner.	In-vehicle equipment could use queue data to avoid routes with delays resulting from queues.
QLD-UN1.02-V01	Minimize Fuel Consumption	A vehicle operator needs knowledge of queues to minimize fuel consumption.	In-vehicle equipment could use queue data to control the approach speed to reduce personal environmental impact and decrease fuel cost.
QLD-UN1.03-V01	Safe Operating Environment	A vehicle operator needs knowledge of queues to foster a safe environment in which to operate a motor vehicle.	In-vehicle equipment could use queue data to allow for a safe approach trajectory to provide for the Operator's physical safety.
QLD-UN1.04-V01	Queue Collision Avoidance	A vehicle operator needs knowledge of queues to know when approaching the end of queue in an unsafe manner.	In-vehicle equipment could use queue data to identify when approaching a queue when on-board sensors are occluded

System Operator			
QLD-UN2.01-V01	Queue Location	A system operator needs knowledge of the location of queue formation on the roadway network.	To pinpoint bottlenecks and determine their cause.
QLD-UN2.02-V01	Response	A system operator needs to execute strategies in response to the formation of queues.	To provide safety, mobility, and/or environmental benefits to drivers.
QLD-UN2.03-V01	Adaptive Signal Timing	A system operator under preset parameters, allows the adaptive traffic signal timing to adjust signal timing to accommodate fluctuating demand.	To minimize cycle failures and traffic spillbacks to upstream intersections, other arterials, or other freeways.
QLD-UN2.04-V01	Strategy Selection	A system operator needs a process for determining which timing strategy would be executed (if more than one strategy is available)	To quickly and decisively implement a strategy.
QLD-UN2.05-V01	Prioritizing Movement	A system operator needs to have a method for prioritizing movement when selecting a strategy (e.g. number of vehicles, number of passengers, type of vehicle, transit schedule adherence, etc.)	To implement a strategy that is in line with agency/regional goals and objectives
QLD-UN2.06-V01	Minimize System Delay	A system operator needs to minimize delay on the arterial network	To improve system performance.
QLD-UN2.07-V01	Smart City Data	A system Operator needs to integrate queue data into smart city connected data platforms.	To encourage third-party use of queue data and to receive queue data from third-party data sources

Related Performance Measures

Agencies can be expected to use preliminary sets of performance measures assess the effectiveness of the detecting and reacting to queues in order to meet agency goals and objectives. These measures are finalized during the development of the Performance Measurement plan, but are included here to provide insight on the methods that would be used to assess the ability of the system to meet agency objectives and hypotheses. Purdue Traffic Signal Performance Measures are an emerging standard for performance measurement and evaluation of signal performance that should be considered moving forward. These signal performance measures have been tied directly to lower costs, higher quality of service to customers, and improved safety and efficiency by USDOT.

Table 2: Preliminary Performance Measure Overview

OBJECTIVE	HYPOTHESIS	PERFORMANCE MEASURE	DATA SOURCE
TBD	TBD	Queue Dissipation Time	CV/ITS data

TBD	TBD	Real-Time Queue Length	CV/ITS data
TBD	TBD	Maximum Queue Over a Cycle	CV/ITS data
TBD	TBD	Minimum Queue Over a Cycle	CV/ITS data
TBD	TBD	Rate of Change at the Back of the Queue	CV data

4.3 Priorities Among Changes

User needs in the previous section are classified as essential, desirable, or optional. Essential user needs are needs that must be met for the system to achieve its goals, while desirable user needs are needs the deploying agency would like the system to address. Not addressing a desirable need does not preclude a particular solution from being developed. Finally, optional needs are available to be developed, but are not obligatory. Different agencies would have different priorities, and this would be reflected in which user needs are placed into each category. For the purpose of this ConOps, all user needs are considered essential.

4.4 Changes Considered but not Included

There are currently no changes considered but not included. This may be amended as further stakeholder feedback is received that may narrow the scope of the system.

5.0 Concept for the Proposed System

5.1 Background, Objectives, and Scope

This section focuses on the vision, goals & objectives, and ultimately how the system addresses stakeholder needs. Specifically, this section describes what the system needs to do that it is not currently doing. As described in Sections 1 and 2, the primary goal of QLD is to be able to provide this input to applications within a CV environment to make those applications more reliable and effective than through vehicle or roadway sensor data alone.

QLD data and the applications it enables would likely result in improved safety for motorized and non-motorized users of the transportation system. This includes a reduced number of crashes and improved accessibility and mobility through a significant reduction in the growth rate of congestion by better managing the available capacity along the corridor. Section 5.3 provides four examples of applications that could be used along arterial corridors or at ramp meter locations that would be enabled through the deployment of a QLD system and the availability of QLD data.

QLD systems could be used to protect and enhance the environment, promote energy conservation, improve quality of life, and promote consistency between transportation improvements and state and local planned growth and economic development patterns. With reduced congestion and a more efficient system, the individual vehicle emissions per trip are expected to be reduced.

Finally, system operators who embrace the deployment of CV environments that include QLD can be expected to have improved efficiency in system management and operation. This efficiency includes reduced travel times and improved reliability along the corridor. This would be identified and measured by a number of factors, but for the purpose of this ConOps, the goal is to provide the information in the SPaT message set or through a data sharing platform managed by the system operator in order to optimize real-time traffic signal timings. The lead agency is the system operator who is responsible for operating the signal and providing these message sets.

The QLD system coordinates with multiple other systems to receive data on vehicle position and status from multiple sources, including infrastructure-based detection and equipped vehicles and probe data systems. The QLD system would collect, process, digitize, and securely send BSM data from vehicles to roadside equipment for edge processing or the Traffic Management Center (TMC)/center for processing and integration with traffic sensor data (e.g., speed, volume, and occupancy) to determine the queue. The system would provide dynamic information to estimate current queue length based on available data, estimate predicted queue length, and provide estimated current and predicted queue length to external systems in near real time. The TMC uses collected data to detect the location, duration, and length of queue propagation, as a result of significant downstream speed reductions or stopped traffic. This would ultimately be disseminated to vehicles and provide opportunities for enhanced traffic signal control, as well as provide support for administration, configuration, monitoring and maintenance of the system.

Vehicle systems with applications that can use QLD would benefit from this information. Interfacing with the driver of the vehicle is not implied; the driver would likely not be aware of the QLD input beyond what may be displayed in the vehicle.

5.2 Operational Polices and Constraints

System Architecture

The proposed system should be expected to conform to existing ITS architecture that provides a framework for the integration and interoperability of the proposed QLD system with existing ITS systems.

Wireless Communications Standards

The proposed system may utilize wireless communications between vehicles and roadside infrastructure to communicate information that enables the system to detect queues on the arterial street network. While there are no constraints on the media, it would be of interest to adhere to pre-existing wireless communications standards to enable any transmission of information between vehicles and the roadside infrastructure (and vice versa).

Vehicle Operation Laws and Regulations

The movement of drivers, bicyclists, and pedestrians are governed through laws and regulations that are set at the state and local levels. The proposed system would be designed in a manner that expects all roadway users to adhere to these laws and regulations. However, exceptions to these laws and regulations must be acknowledged and considered.

Physical Constraints

The ability of the system to function as intended would likely require interfacing with existing ITS systems, including existing SPaT and MAP message broadcasting capabilities. In order for this to occur, access to the existing traffic signal system must be provided at the location where physical infrastructure (part of the new system) would be deployed. It is assumed that existing systems would be capable of providing the types of information needed by the proposed system to function as intended. Alternatively, the existing system could be upgraded to accommodate the data needs of the proposed system. Furthermore, it is assumed that the deployment of hardware on the roadside can be accommodated through existing or planned physical mounting of infrastructure.

Network and Data Security

A system that utilizes wireless communications between vehicles and infrastructure would need to ensure that those communications are secure and trustworthy (i.e., originate from a reliable source). Existing information technology practices need to accommodate the addition of wireless communications technology, if it is used. Efforts to ensure that communications cannot be compromised would be increasingly important in a CV environment.

The system would rely on the transmission of data that could be used to identify an individual, otherwise known as personally identifiable information. To account for this and ensure that privacy laws and regulations are met, the system should adhere to federal guidance and other best practices regarding the use and filtering/aggregating/removal of personally identifiable information, should it be saved. If they do not exist, the lead agency should consider establishing a data policy.

5.3 Description of the Proposed System

This section provides a systems level overview of the QLD system to be developed including the users of the system, what the system interfaces with, the planned capabilities, and the system architecture. The physical operational environment in terms of facilities, equipment, computing hardware, software, personnel, operational procedures and support necessary to operate the deployed system is provided.

The operational environment for this use case is a heavily traveled, mixed-use, principal arterial corridor as shown in the images in Appendix A. As shown in Figure 2, the system of interest, which includes the QLD system, interfaces with four key elements: 1) roadside equipment, 2) CVs, 3) system operator, and 4) data fusion companies. The focal elements of the system diagram are shown with a bold black border in the diagram: in-vehicle equipment, CV roadside equipment, and the QLD system.

Note: This image is the same as previously shown in Figure 1.

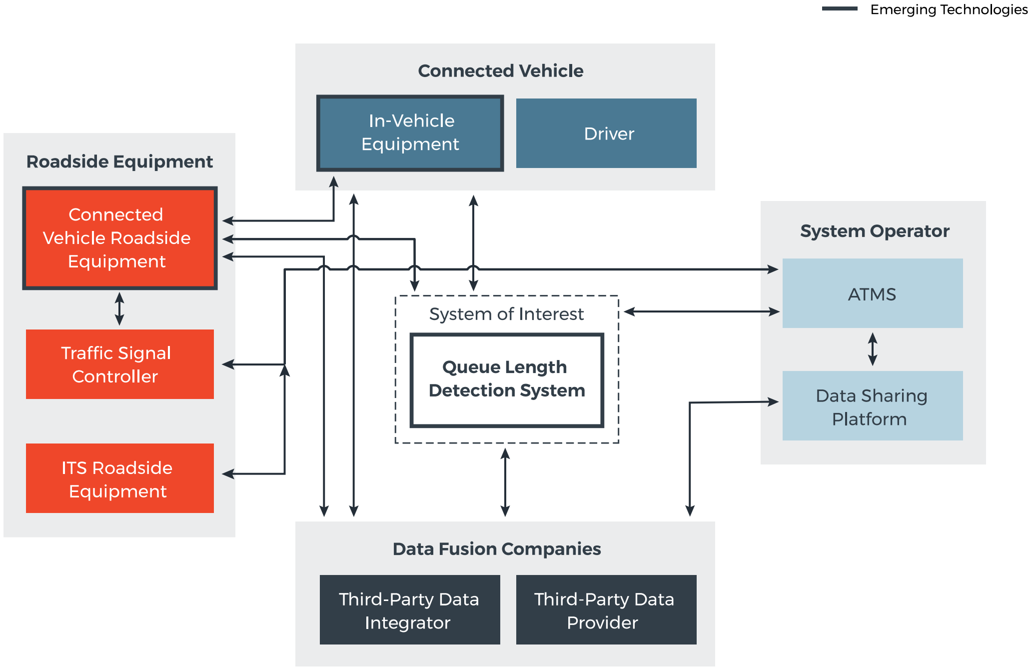


Figure 2: Queue Length Detection System Diagram

Queue Length Detection System

The QLD system would work within the arterial roadway system and the system functions together with multiple physical objects, which can be categorized into vehicle, roadside, and center objects. A QLD processor would be the responsibility of the system operator and would likely reside in either the TMC (central processing, part of an ATMS) or would be co-located with other roadside equipment (distributed processing). It would collect detection data from ITS roadway equipment, CV roadside equipment, and other vehicle position data from third-party data services (or the Data Management Center), fuses this data, and determines the location of queues. The TMC and/or ITS Roadside subsystem could utilize the queue information for a number of use cases, described later in this section. The QLD processor may also reside on CV roadside equipment to allow for edge processing of the data.

Additional elements of the system are included in the following sections.

Connected Vehicle

The area of the diagram that is shaded blue shows the CV's role in the system. This includes in-vehicle equipment and the driver. Through integration with existing ITS roadside equipment, the QLD system would be able to take into consideration combinations of equipped and unequipped vehicles; however, the focus here is on how CVs can be used to provide this information. Assumptions include the following:

- Vehicles contain in-vehicle equipment that can communicate with roadside equipment over a short range. Examples of this technology include DSRC and C-V2X.
- Vehicles contain in-vehicle equipment that can wirelessly communicate with third-party data providers over a long range, including cellular (4G, 5G).
- Vehicles contain in-vehicle equipment that is capable of short-range and long-range wireless communications (see descriptions above).
- Unequipped vehicles are not able to communicate with CV roadside equipment or third-party data providers. They are capable of being detected by ITS roadway equipment. Drivers in unequipped vehicles receive information via ITS roadside equipment (if available) to enable queue-detection-based applications.
- In-vehicle equipment may interface with the vehicle data bus to obtain information about the vehicle's location and motion and receives information from the onboard obstruction detection system (e.g., LiDAR, radar, camera). In-vehicle equipment has an interface to provide the driver with audio or visual information, which is understood to be a large, ongoing research problem in itself that the auto manufacturers are working to address.
- In-vehicle equipment is intended to communicate only with infrastructure to interface with the QLD System. It is not the intent of this ConOps to enable queue-related applications using vehicle-to-vehicle communications.

Roadside Equipment

The area of the diagram that is shaded orange shows how roadside equipment interacts with the system. This includes CV roadside equipment, traffic signal controller, and ITS roadside equipment.

CV Roadside Equipment. These devices are the data collectors and disseminators that relay information about the queue to control centers and vehicles via a wireless communication medium. CV roadside equipment interfaces with the traffic signal controller to receive information about the signal state, and to allow modifications to be made to signal timing based on the detection of a queue.

CV roadside equipment exchanges data with CVs via two-way communications radios between the infrastructure-based RSU and the vehicle onboard unit (OBU). The U.S. Department of Transportation (USDOT) has developed communication standards for data exchanges between RSU and OBU (SAE J2735) and specifications for v4.1 RSU. The QLD system would adhere to the standards developed for CV communications. SAE J2735 messages that are used in detecting queues or disseminating queue information include the following:

- Basic Safety Message (BSM) information (e.g., vehicle size, position [latitude, longitude, altitude], speed, heading, acceleration, and brake system status) are transmitted.
- Signal Phase and Timing (SPaT) message transmits from RSU to OBU to convey the signal state of the connected intersection. Queue length information outputted from QLD would be included in SPaT broadcasts.
- MAP message, which provides intersection geometry information, allows a driver or an in-vehicle device to position itself in the roadway environment in relation to other important roadway features, and correctly locate the queue or back of queue.
- Correction information is positioned so that the in-vehicle equipment can correct any data received from Global Navigation Satellite System equipment before utilizing it for other purposes.

Traffic Signal Controller. The traffic signal controller is the "brain" of the intersection. Modern controllers are capable of fully actuated operation, producing signal timings that vary depending on the level of traffic demand. The controller uses settings that have been programmed inside it, along with the vehicle demand for each phase as presented to it by vehicle detectors, to make decisions on the allocation of green time to the various phases.

ITS Roadside Equipment. This includes equipment that monitors and controls traffic as well as monitors and manages the roadway itself. Along an arterial roadway system, equipment examples include traffic detectors, traffic signals, dynamic message signs, closed-circuit television cameras and video image processing systems, grade crossing warning systems, and ramp metering systems. The equipment could also provide environmental monitoring, including sensors that measure road conditions, surface weather, and vehicle emissions and work zone surveillance, traffic control, driver warning, and work crew safety systems.

ITS roadside equipment consists of hardware to collect information about vehicles and pedestrians from detectors (e.g., loop and pedestrian push buttons) and/or from infrastructure-based sensors (e.g., camera and/or radar sensors) and traffic signal controller with control software to manage traffic based on vehicle and pedestrian detection. The controller can be configured by traffic engineers with different control modes (e.g., fully actuated, pre-timed, coordinated with time-of-day plans, or adaptive to prevailing traffic conditions). Under coordinated control where groups of intersections work together to manage traffic, local controllers can communicate with either a field master controller via wired interconnection (e.g., distributed system) or the TMC via backhaul communication (e.g., centralized system) to select the appropriate coordination timing plan.

System Operator

The area in green shows the elements that the system operator of the roadway network is responsible for. These elements include the QLD system and the following:

Advanced Traffic Management System. An ATMS would be integrated into the system operators. TMC and would be part of the system components. It monitors and controls both traffic and the road network. The TMC communicates with the ITS roadway equipment and CV roadside equipment. The TMC monitors the condition of the arterial roadway regarding the environmental conditions and the status of the field devices and then may manage traffic during recurring and non-recurring congestion.

Data-Sharing Platform. The data-sharing platform represents a repository used to disseminate and ingest real-time smart city data. Data made available via this platform is expected to be used to promote safety, mobility, and environmental applications, such as those discussed later in this section. For the purposes of this ConOps, the QLD system would provide information that can be leveraged by third-party data providers, and third-party data providers can then provide data that can be leveraged by the queue detection system. However, other systems and entities may provide data to this system.

CV-related data may be delivered from the Infrastructure Owner Operators (IOOs) to third-party providers in many ways. The project would look at the types of CV data that CV PFS members and other IOOs are working with that might interest third parties and work with the third parties to document consistent methods of data sharing that would be common across IOOs and again common across third-party providers.

Data Fusion Companies

The final element of the system diagram, shown in purple, shows how data fusion companies interact in the system. This includes both third-party data integrators and third-party data providers. The difference between these two is that the integrators have systems that integrate data coming from vehicles and/or the infrastructure, while the providers do not. The data integrators represent data providers who can fuse large and diverse sets of transportation data together, typically through the use of artificial intelligence. These companies are now able to integrate data coming from vehicles and the infrastructure, which expands upon previously available data from third-party data providers, who typically offer services that obtain traffic system data from traffic management systems (among other sources of data), process/aggregate it, and provide it to travelers through a smartphone app.

In exchange for the access to QLD data, data fusion companies and third-party data providers may be required to reciprocate by providing its processed outputs to the data management platform, so it can be used by the QLD system. The end-user of these applications would be required to have a connection to the internet (via a wireless service provide) to access the data from these services. Information regarding the formation of queues provides benefits to drivers, such as those enabled through applications discussed later in this section.

Communication

The arrow in the diagram indicates communication between the different system elements. It is important to note that the QLD system considers multiple methods of detecting queues and disseminating information to drivers. Queue detection could be enabled through ITS roadway equipment, CV roadside equipment, and third-party data providers. Similarly, information that enables safety, mobility, and environmental applications would be provided to the driver via these same methods. Information provided via CV roadside equipment and third-party data providers would require use of an in-vehicle device, which would receive data from these services wirelessly and provide a notification to the driver. ITS roadside equipment is static in nature and can provide information to the driver at fixed locations along the arterial network or at ramp metering locations.

Arterial Queue Applications

Expanding on these system elements, four applications have been developed to demonstrate the ability of the system to meet the needs of users, as defined in Section 4.2. For the purpose of this ConOps, use cases tend to have a common method of queue detection and action taken. To understand how these use cases play out under differing sets of initial conditions and modes of operations, see Section 6, “Operational Scenarios.”

- **Application 1 – Traffic Signal Adjustment (Queue Flush)**

  The Traffic Signal Adjustment application uses sensors and wireless data communications to detect queues along arterial roadways or at ramp meter locations in real-time and enables lead agencies to adjust traffic signal timing to enable the queue to clear. If a real-time detection system has been deployed with available live feeds, then the lead agency operator can view the queue lengths and make real-time adjustments to signal timing. If such a system has not been deployed, the lead agency does not receive queue length information and cannot react to changes in real-time. The traffic signals generally operate with non-adaptive features and are interconnected to promote vehicle progression through coordinated signal timing along a corridor.

  The basic premise of this application is to detect where a queue is forming at an approach to an intersection and to provide a priority or preemptive call for the traffic signal timing phase associated with the approach on which the queue is forming. The signal phase for the particular approach experiencing the queue would stay green until the queue dissipates or a preconfigured maximum flush period is reached.

  It is important to consider that flushing a queue results in a large immediate influx of demand on downstream intersections, which could result in the queue to re-form in a different location. Neighboring signals that have independently functioning queue detection and flushing would eventually clear the string or platoon of vehicles (that form the queues) from the corridor, but ideally, changes in signal timing throughout the system would be coordinated in such a fashion that allows the string or platoon to make its way through the transportation network without the queue reforming.

Also, when multiple queues form on different approaches at an intersection, there should be a method for prioritizing where queues are flushed first. Priority for queues that can be flushed simultaneously (i.e., non-conflicting movements, which depends on the signal phasing capabilities) should be additive. Examples include the following:

- Left, through, and right-turn movements in the same approach group

- Through and right-turn movements on opposing approach groups

- Opposing left-turn movements and complementary right-turn movements (if protected left / right turns movements are available)

Management agencies could use a number of factors to weigh the priority level of each queue. The number of vehicles is one method that could be used, but depending on local priorities, examples of cases where additional weight may be given include but are not limited to the following:

- Vehicles with more occupants (weight is proportional to occupancy; e.g., transit vehicles, or carpools)
- Transit vehicles running behind schedule (greater weight for increased delay)
- Strings or platoons of automated vehicles (greater weight given because queues with AVs can be serviced more quickly – less lost time)
- Freight vehicles (in areas where freight movements are prioritized; e.g., industrial area or intermodal terminal)

For the QLD system to provide outputs that contain these attributes of a queue, the system would need access to information that can be used to calculate these attributes.

- **Application 2 – End of Queue Eco-Approach**

  The End of Queue Eco-Approach application uses sensors and wireless data communications to detect queues along arterial roadways or at ramp meter locations and encourages environmentally friendly approaches to the backs of queues. Prior to arriving at the back of the queue, the in-vehicle equipment would determine a recommended speed at which to travel in order to minimize the amount of fuel used. Automated technology available to the vehicle would use this recommended speed to provide vehicle longitudinal control. There are two methods by which environmental benefits could be realized. First, by reducing speed, the vehicle does not unnecessarily remain at high speed, consuming fuel, only to come to a stop at the back of the queue. Second, under certain conditions, a speed is recommended such that the vehicle approaches the end of the queue as the speed dissipates. This prevents the vehicle from coming to a complete stop, reducing the need to accelerate from a stop. Accelerating from a stop does not provide for an efficient burning of fuel, releasing greater proportions of carbon monoxide and other volatile organic compounds (which have a greater carbon dioxide equivalent) in the atmosphere as exhaust.

The benefits of this application are greatly predicated on the use of internal combustion engines. As the vehicle fleet increasingly becomes electric and as the power supplied is derived from non-polluting sources, the less of an environmental impact this application would have, which may extend battery charge life.

- **Application 3 – End of Queue Approach Warning**

  It is the intent of the End of Queue Approach Warning application to prevent rear-end or secondary collisions at the end of queues along arterial roadways or at ramp meter locations. This application would utilize ITS and wireless communications technologies to enable a vehicle at the rear of a queue, roadside equipment, or a third-party data service to automatically broadcast queue status information to upstream vehicles. As the upstream vehicles along the arterial reach the back of the queue, a notification would be provided to drivers to make them aware of the upcoming queue.

  To enable this application, the system must be capable of detecting the rear vehicle in the queue. Information regarding the location of this vehicle (e.g., latitude/ longitude, roadway, lane number) is then provided to the approaching vehicle, and the driver is notified at a time and location that gives them enough time to take a measured, safe action.

- **Application 4 – Traffic Signal Priority**

  As priority eligible vehicles approach intersections where they are requesting traffic signal priority (e.g., emergency vehicle, transit, and/or trucks), there may be a standing queue between the vehicle and the intersection stop bar that would require earlier signal actuation to provide the best benefit to the vehicle being served. Priority control algorithms/logic, such as in MMITSS, can consider the need to clear a queue in the decision-making logic.

  To enable this application, the QLD system must be capable of detecting the rear vehicle in the queue in each lane (since lane-based queue determines the time needed in the vehicles lane). This information would be provided to the priority control algorithms that would be located at each intersection as part of the ITS or CV roadside equipment or integrated with the Traffic Signal Controller.

5.4 Modes of Operation

Three distinct modes of operations have been identified:

- **Mode 1 - Normal Operating Conditions**

  Normal operating conditions indicate the QLD system is functioning as intended, generating outputs as intended, and not generating outputs when unnecessary. Drivers would be expected to adhere to existing laws and regulations associated with traffic control devices (e.g., traffic signals, signage, and lane markings) with the added benefit of information and notifications that complement these laws and regulations.

- **Mode 2 - Low CV Penetration**

  End-of-queue spatial accuracy is predicated on a certain penetration of CVs reaching the back of the queue. If there are not enough CVs on the roadway, the end of the queue may not be properly captured by the queue detection system. In this case, the detected queue may be longer or shorter than ground truth. The systems or subsystems that ultimately utilize QLD data would not function as intended.

- **Mode 3 - Failure Condition with Diminished Communications**

  A number of conditions may cause non-normal operations of the system, which may include, but are not limited to wireless signal attenuation, wireless interference/congestion, loss of power, and loss of connectivity with supporting systems. These conditions prevent the transmission of data (in a timely manner) that is required for an application to provide benefits to users as intended.

  Furthermore, the ability of a vehicle to accurately position itself is a critical aspect of being able to accurately determine the end of the queue. Inaccurate data regarding the location and motion of vehicles could result in an inaccurate location of the end of the queue, and could provide inaccurate information regarding critical attributes of a queue, including its elasticity.

5.5 User Classes and Other Involved Personnel

The user classes and involved personnel are nearly the same as those for the existing system; AVs able to communicate in a CV environment would create a new user class to consider.

5.6 Support Environment

The current and planned physical support environment includes staffing and training, evaluation, operational procedures, outreach, and policies needed to support a successful rollout of a QLD system. These policies are summarized into two categories:

- **Security.** Trusted and secure vehicle-to-infrastructure and vehicle-to-vehicle communications, such as those using a Security Credential Management System (SCMS), are essential for CV applications. QLD would focus on data gathering, processing and fusion, and data assembling. The QLD system would interface with the SCMS if it is in place while the implementation of SCMS is independent and separate from QLD implementation.

  Data sharing and/or archiving of various data sources for QLD and outputted queue length estimation would be part of the QLD system for monitoring and evaluation of the system performance. Data archiving can be designed to be configurable by the operating agency with local data archiving policy.

- **Deploying Agency Impacts.** The deploying agency typically acts as the system operator who is responsible for the TMC and would be the owner/operator of the CV roadside equipment, ITS equipment, and central control software. Also, the agency would collect data generated by the system and be subject to decision making on how to process, store, and destroy this data.

The deploying agency is responsible for coordinating with ITS equipment vendors to upgrade existing ITS equipment that is capable of interfacing with the proposed system. Replacing equipment or upgrading firmware is a common practice. The deploying agency is also responsible for coordinating with signal system or ITS contractors regarding the installation of roadside infrastructure. This includes, but is not limited to the threading of cable, mounting of hardware on span wire and mast arms, and networking of all roadside components. The deploying agency is also responsible for distributing and installing in-vehicle devices should they be procured in conjunction with other system components. Finally, the deploying agency is responsible for maintaining the fiber or other communication infrastructure (backhaul that provides connectivity between the TMC, QLD system, ITS/CV roadside equipment) and the accompanying transportation network management systems.

6.0 Operational Scenarios

This section presents scenarios that capture how the QLD system serves the needs of users when the system is operating under various modes of operation. The scenarios are grouped into use cases, which correspond to each proposed application (described in Chapter 5). Scenarios for each use case describe how the application would operate under various types of conditions and under different modes of operations: normal operating conditions and degraded and/or failure conditions, as necessary.

These use cases are intended to describe only external events that pertain to how the QLD system would benefit transportation system users, and would minimize specifying details regarding the internal workings of the system; scenarios are developed in this fashion to allow for flexibility in developing requirements and design of the QLD. Design constraints provided in the previous chapter are detailed in the scenarios.

6.1 Use Case 1 – Scenario 1

This use case considers typical off-peak flows on arterials that may include some congestion corresponding to land uses but not related to standard roadway peak hours. The user's travel time along the corridor is generally unaffected by congestion, and traffic signal timing plans are either set for actuated timing or preset timing balancing the traffic from all directions, or could be coordinated along an arterial. The arterial roadway is managed by the lead agency with coordination with other stakeholders.

Table 3: Use Case 1, Scenario 1

USE CASE	**TRAFFIC SIGNAL ADJUSTMENT**	
Scenario ID and Title	Normal Operating Conditions – Single Queue Formation	
Scenario Objective	▪ Alter traffic signal timing to service a queue more quickly than a preset timing plan using CV data.	
Operational Events	▪ Detect queue, and the applicable movement, and intersection phase. ▪ Execute queue flushing for the movement. ▪ Modify operations at downstream intersections in anticipation of influx of demand.	
Actors	**ACTOR**	**ROLE**
	Vehicle Operator	Traverse the roadway network in an efficient fashion.
	System Operator	Provide a quick demand management response to a detected traffic issue.
Pre-Conditions	▪ A large weekend recreational sporting event has just ended. Several hundred vehicles enter the arterial roadway network over the course of 30 minutes. Attendees live all over the metro area - many traveling toward the nearest freeway. ▪ The quickest route to the freeway is via the arterial roadway network where a queue detection system is installed. This is enabled via roadside ITS, roadside CV (requires in-vehicle CV equipment), or third-party data providers (requires vehicle to contain equipment capable of communicating with third-party data provider). ▪ There are already a number of other vehicles on the road with many people running weekend errands and visiting restaurants in the area. ▪ System Operators have the ability to remotely adjust signal timing.	
	SOURCE	**KEY ACTION**
	Vehicles	▪ The approach intersection is on an arterial. The intent is to make a through movement (toward freeway).

Key Actions and Flow of Events	Traffic Signal Controller	▪ The traffic signal controller maximizes green time on the approach, but is limited by the configuration of the current traffic signal timing plan.
	General	▪ Because the demand of vehicles is greater than the ability of the intersection to serve the demand, a queue begins to form.
	Queue Length Detection System	▪ The system receives vehicle location and motion data. This data is received from ITS roadside equipment and from in-vehicle equipment (via CV roadside equipment or via the data management platform/third-party data provider) ▪ The system determines that a queue is forming.
	Queue Length Detection System	▪ The system uses intersection geometry data to determine which approach the queue is forming on and which intersection phase needs to be served to clear the queue.
	General	▪ Beyond preconfigured flushing threshold, the queue extends past a preconfigured threshold length and continues to grow.
	Queue Length Detection System	▪ The system determines that the queue length has exceeded the preconfigured threshold. (Note: Queue length is not the only parameter that could be used and is used here for illustrative purposes only.) (Note: The queue could be determined by looking at the density and average speed of traffic in the approach segment.)
	Queue Length Detection System	▪ The system sends a preemption call to the traffic signal controller. The preemption call allows the signal to “flush” for an amount of time equivalent to the queue length up to the maximum green time allowed in the signal timing plan.
	Traffic Signal Controller	▪ The controller receives preemption call, and proceeds to the preemption phase at the earliest available opportunity (i.e., allows current phase to clear).
	General	▪ Queued traffic proceeds through intersection and the queue begins to dissipate from the front of the queue.
	Queue Length Detection System	▪ The system detects movement of traffic as it passes through the intersection. This information is passed to the subsequent intersections, so that it may take advance action in preparation for the arriving string or platoon of vehicles.
	Traffic Signal Controller	▪ The controller reaches the end of the preemption period and resumes normal signal timing plan. It may take multiple cycles to “recover” back into normal operations.
	General	▪ As the traffic signal controller services other phases, the queue begins to re-form. However, local signal timing policy may require other phases to be served for a minimum period of time before allowing preemption to be placed on the same phase again.
	Queue Length Detection System	▪ The system constantly determines the queue length, and places a call to the traffic signal controller to request preemption. If the signal controller is still servicing other phases, it places overriding preemption calls to the traffic signal controller as the queue continues to grow.
	General	▪ Repeat Steps 9-14 until the queue has dissipated and preemption calls are no longer being placed to the traffic signal controller.

Post-Conditions	- Queues resulting from influx of event traffic are more efficiently dissipated than it is under the current system.
Policies and Business Rules	- Signal timing configuration policy
Traceability	- QLD-UN1.01-v01 Minimize Delay - QLD-UN2.01-v01 Queue Location - QLD-UN2.02-v01 Response - QLD-UN2.03-v01 Adaptive Signal Timing - QLD-UN2.06-v01 Minimize System Delay
Summary of Inputs	- Intersection geometry (includes phase to lane mapping and egress-to-ingress mapping for adjacent intersections) - Vehicle location and motion data - Signal timing strategies (parameters)
Summary of Outputs	- Detected queue information - Preemption call to signal

6.2 Use Case 2 – Scenario 1

This use case considers how information from the CVs can be used to influence a vehicle’s speed in a way that reduces its acceleration and deceleration (“eco-driving”) beyond the typical range of short-range wireless communications.

Table 4: Use Case 2, Scenario 1

<table>
<tr><th>USE CASE</th><th colspan="2">VEHICLE-ENABLED END OF QUEUE ECO-APPROACH</th></tr>
<tr><td>Scenario ID and Title</td><td colspan="2">Non-congested (off-peak)</td></tr>
<tr><td>Scenario Objective</td><td colspan="2">▪ Assist a driver in approaching the rear of a queue in an eco-friendly manner.</td></tr>
<tr><td>Operational Events</td><td colspan="2">▪ Detect queue and an approaching vehicle’s location with respect to the queue.
▪ Provide recommended speed that allows vehicle operator to minimize energy consumption as they approach the queue.</td></tr>
<tr><td rowspan="3">Actors</td><td>ACTOR</td><td>ROLE</td></tr>
<tr><td>In-Vehicle Equipment</td><td>Minimize environmental impact, reduce fuel costs</td></tr>
<tr><td>Driver</td><td>Enable eco-driving on vehicle</td></tr>
<tr><td>Pre-Conditions</td><td colspan="2">▪ An unusually long queue forms in advance of an intersection. Traffic in advance of the queue typically moves at a high rate of speed (e.g., 45 mph or greater).
▪ A driver is approaching the end of the queue on an arterial roadway where a queue detection system is installed. This is enabled via roadside ITS, roadside CV (requires in-vehicle CV equipment), or third-party data providers (requires in-vehicle CV equipment).</td></tr>
<tr><td rowspan="4">Key Actions and Flow of Events</td><td>SOURCE</td><td>KEY ACTION</td></tr>
<tr><td>Vehicle Operator</td><td>▪ Approaches rear of queue.</td></tr>
<tr><td>Queue Length Detection System</td><td>▪ Receives vehicle location and motion data. This data is received from ITS roadside equipment and from in-vehicle equipment (via CV roadside equipment or via the data management platform/third-party data provider). It detects that a queue has formed and makes information regarding the location of the queue available (via roadside equipment or third-party data providers).</td></tr>
<tr><td>In-Vehicle Equipment</td><td>▪ The equipment receives information regarding the queue from the queue detection system, and receives information about the vehicle’s location and</td></tr>
</table>

		motion via the vehicle system (e.g., CAN Bus) or Global Navigation Satellite System
	In-Vehicle Equipment	▪ The equipment determines the distance between the vehicle's location and the back of the queue. Once the vehicle is less than a preconfigured distance threshold from the rear of the queue, it issues a queue approach notification to the vehicle operator with a recommended approach speed. As the vehicle moves closer to the rear of the queue, the recommended speed is decremented. The vehicle operator is encouraged to coast (not use gas) to achieve the recommended speed.
	In-Vehicle Equipment	▪ The equipment adjusts speed to match recommended speed by coasting.
	General	▪ A traffic signal controller executes a preempt flush strategy, allowing the queue to begin to flush from the front. See Use Case 1, Scenario 1 for more information.
	Queue Length Detection System	▪ The system continues to receive vehicle location and motion information from vehicles in the queue and continues to provide information regarding the location of the queue available.
	In-Vehicle Equipment	▪ The equipment determines that the queue is about to dissipate. However, at the current recommended approach speed, the vehicle would arrive at the back of the queue before it dissipates.
	In-Vehicle Equipment	▪ The equipment determines that the vehicle would have to arrive at the back of the queue 30 seconds later than it would if it follows the current recommended speed strategy. An updated recommended speed strategy is devised to allow the vehicle to arrive at the end of queue location just after it dissipates
	In-Vehicle Equipment	▪ The equipment adjusts speed to match recommended speed by coasting and reaches location where end of queue recently dissipated.
	In-Vehicle Equipment	▪ The equipment notifies vehicle operator that they may resume speed
	In-Vehicle Equipment	▪ The equipment resumes speed to prevailing conditions. Note at this point, the vehicle operator should be close to the preceding vehicle
	Queue Length Detection System	▪ The system may provide overriding signal preemption call to account for additional vehicle that is now traveling with the "flush" string or platoon.
Post-Conditions	▪ In-vehicle equipment controls the vehicle and makes energy-efficient approach to intersection. ▪ Vehicle does not have to come to a complete stop, providing further environmental benefit.	
Policies and Business Rules	▪ Signal timing configuration policy	
Traceability	▪ QLD-1.02-v01 Minimize Fuel Consumption	
Summary of Inputs	▪ Vehicle location and motion data	
Summary of Outputs	▪ Detected queue information ▪ Recommended Approach Speed	

6.3
Use Case 3 – Scenario 1

This use case considers how information from the CVs can be used to warn and/or slow a vehicle’s speed when a queue is unable to be seen by the driver due to limited vertical sight distance, roadway curvature, or due to driver distraction.

Table 5: Use Case 3, Scenario 1

USE CASE	**END OF QUEUE APPROACH WARNING**	
Scenario ID and Title	Normal Operating Conditions (off-peak)	
Scenario Objective	▪ Provide safety critical information as a vehicle approaches the end of a queue when line of sight may be limited for the vehicle.	
Operational Events	▪ Detect queue and an approaching vehicle’s location with respect to the queue. ▪ Warn vehicle operator of a potentially unsafe event as they approach the rear of the queue.	
Actors	**ACTOR**	**ROLE**
	Vehicle Operator	Safely traverse the roadway network
Pre-Conditions	▪ An unusually long queue forms in advance of an intersection. Traffic approaching the queue typically moves at a high rate of speed. ▪ Vertical or horizontal curvature of the roadway creates limited line of sight. ▪ A vehicle operator is approaching the end of the queue on an arterial roadway where a queue detection system is installed. This is enabled via roadside ITS, roadside CV (requires in-vehicle CV equipment), or third-party data providers (requires vehicle to contain equipment capable of communicating with third-party data provider).	
Key Actions and Flow of Events	**SOURCE**	**KEY ACTION**
	Vehicle Operator	▪ The operator approaches rear of the queue. The end of queue may be in the vehicle operator’s field of view, but the vehicle operator is not paying close attention, or the queue may not be immediately visible to the vehicle operator.
	Queue Length Detection System	▪ The system receives vehicle location and motion data. This data is received from ITS roadside equipment and from in-vehicle equipment (via CV roadside equipment or via the data management platform/third-party data provider). The system detects that a queue has formed, and makes information regarding the location of the queue available (via roadside equipment or third-party data providers).
	In-Vehicle Equipment	▪ The equipmentn receives information regarding the queue from the queue detection system, and receives information about the vehicle’s location and motion via the vehicle system (e.g. CAN Bus) or Global Navigation Satellite System
	In-Vehicle Equipment	▪ The equipment provides a notification to vehicle operator that they are approaching the end of a queue once the vehicle is within a preconfigured distance threshold of the end of the queue.
	In-Vehicle Equipment	▪ The equipment receives notification of queue ahead and adjust speed accordingly.
	In-Vehicle Equipment	▪ The equipment continues to receive information regarding the queue from the queue detection system, and receives

		information about the vehicle's location and motion via the vehicle system (e.g. CAN Bus) or Global Navigation Satellite System
	In-Vehicle Equipment	▪ The equipment determines the distance between the vehicle's location and the back of the queue. Once the vehicle is less than a distance threshold from the rear of the queue, it issues a queue approach warning to the vehicle operator. This is a higher-priority alert and takes precedence over the notification (see Step 7). The distance threshold is a function of the vehicle's speed. Note: This warning is much more urgent in nature, and must be enabled through an in-vehicle device.
	In-Vehicle Equipment	▪ The vehicle decreases speed. The driver or vehicle eventually becomes un-occluded from the queue, perceives the queue, and safely comes to a safe stop at the rear of the queue based on perception/detection of the queue
Post-Conditions	▪ The vehicle operator properly reacts to the warning and safely avoids rear-end crash at rear of queue.	
Policies and Business Rules	▪ None	
Traceability	▪ QLD-UN1.03-v01 Safe Operating Environment ▪ QLD-UN1.04-v01 Queue Collision Avoidance	
Summary of Inputs	▪ Vehicle location and motion data	
Summary of Outputs	▪ Detected queue Information ▪ End of queue approach notification and warning	

6.4 Use Case 4 – Scenario 1

This use case considers the scenario where a priority eligible vehicle, e.g. emergency vehicle, transit, or truck, is approaching a signalized intersection, it is requesting traffic signal priority, and there is a queue between the vehicle and the intersection stop bar that needs to be cleared for the vehicle to clear the intersection with minimal delay.

Table 6: Use Case 4, Scenario 1

USE CASE	**TRAFFIC SIGNAL PRIORITY**	
Scenario ID and Title	Normal Operating Conditions – Single Priority Vehicle Request for Priority	
Scenario Objective	▪ Provide early green to clear a queue before a priority eligible vehicle is served.	
Operational Events	▪ Detect queue in the service lane. ▪ Inform the priority control algorithm/logic about length of queue. ▪ Provide early green to clear queue before vehicle arrives at the back of the queue.	
Actors	**ACTOR**	**ROLE**
	Priority eligible Vehicle Operator	Traverse the roadway network in an efficient fashion.
	System Operator	Provide additional green split/maximum time to allow queue and priority eligible vehicle to clear signalized intersection.
Pre-Conditions	▪ A transit vehicle is running more than 3 minutes behind schedule and is requesting traffic signal priority as it approaches signals in a corridor.	

	▪ Queues exist at the downstream signal that could delay the vehicle from clearing each intersection efficiently. ▪ There are no transit stops between the vehicles current location and the next signal(s). ▪ Transit signal priority is enabled and programmed to accommodate queues and transit vehicles.	
Key Actions and Flow of Events	**SOURCE**	**KEY ACTION**
	Vehicles	▪ Vehicles approach intersection on arterial, intend to make a through movement.
	Traffic Signal Controller	▪ The controller provides traffic signal timing based on the operating agencies policy for coordination and priority control
	General	▪ A queue has formed in the transit service lane (e.g. right curb lane).
	Queue Length Detection System	▪ The system receives vehicle location and motion data. Determines this data is received from ITS roadside equipment and from in-vehicle equipment (via CV roadside equipment or via the data management platform/third-party data provider). It determines that a queue is forming.
	Queue Length Detection System	▪ The system uses intersection geometry data to determine the lane queue length.
	General	▪ The transit lane queue extends to be a certain length and would take a certain amount of time to clear.
	Queue Length Detection System	▪ The system communicates the real-time lane queue length to the traffic signal priority system
	Traffic Signal Priority System	▪ The system computes the time to clear the queue and before the vehicle would arrive at the stop bar and tells the traffic signal controller when to start the green service phase
	Traffic Signal Controller	▪ The controller receives the request from the Traffic Signal Priority system and provide green as early as feasible
	Vehicles	▪ The vehicle receives a green signal and the queue discharges.
	Queue Length Detection System	▪ The system monitors the queue discharge rate to determine when the queue would clear.
	Transit Vehicle	▪ The vehicle arrives at the intersection stop bar as the last car in the queue clears the intersection.
	General	▪ As the traffic signal controller services other phases, the queue begins to re-form.
	General	▪ The intersection returns to normal traffic control policy (e.g. coordination, free, fixed time).
Post-Conditions	Queues may have grown on non-transit service phase and require additional time to clear.	
Policies and Business Rules	▪ Traffic Signal Priority Control Policy	
Traceability	▪ QLD-UN1.01-v01 Minimize Delay ▪ QLD-UN2.01-v01 Queue Location ▪ QLD-UN2.02-v01 Response ▪ QLD-UN2.03-v01 Adaptive Signal Timing ▪ QLD-UN2.06-v01 Minimize System Delay	
Summary of Inputs	▪ Intersection geometry (includes phase to lane mapping and egress-to-ingress mapping for adjacent intersections) ▪ Vehicle location and motion data ▪ Signal timing strategies (parameters) ▪ Transit vehicle lane information	

	▪ Transit stop location information
Summary of Outputs	▪ Detected queue information ▪ Request to traffic signal controller for additional green time
Alternate Flows	▪ Multiple priority vehicles approaching from different directions ▪ Closely spaced intersections so that downstream queue management is required

7.0 Summary of Impacts

This section describes the proposed system based on the impacts on each of the stakeholders.

7.1 Operational Impacts

- System operators receive higher-quality queue data that can be used for applications that rely on the ability to detect a queue.
  - Alternative queue detection methods
- Addition of strategies to handle the formation of queues
  - Mobility: Traffic Signal Adjustment (Queue Flushing)
  - Environmental: Driver-Enabled End of Queue Eco-Approach
  - Safety: End of Queue Approach Warning
- New information pathways for providing queue-related information to drivers
  - Short-Range wireless communications
  - Long-Range wireless communications
- Vehicles receive information that is spatially and temporally relevant to them. (i.e., the display of information to a driver is based on their specific location and motion and the location of queues in the system)

7.2 Organizational Impacts

Staffing and Training

Since the QLD system relies on new forms of data collection and uses new types of roadside equipment, there would be an impact on the operating agency's workforce. As is the case when any new CV applications or technologies are deployed, there would be a need to train existing staff and possibly hire new staff to support QLD system deployment.

The biggest impact would be on TMC operators and IT support personnel responsible for managing the new forms of traffic data from CVs. All of this data would need to be captured and stored in a secure environment and integrated with existing forms of traffic data to create accurate estimates of queue length. This may require having a full-time data scientist in the TMC, if the workload requires it. Also, maintenance personnel and network operators would have to be trained to keep the infrastructure components of the system fully operational. New types of equipment such as roadside units may have to be added to the agency's existing maintenance program. Finally, the traveling public may require education to better understand the new equipment and the capabilities within their vehicles.

Evaluation

The QLD system would need to be continuously monitored and reviewed for improvement. Since QLD relies on new types of data and new algorithms, there would likely be some growing pains, so policies and a rigorous evaluation plan should be in place to make sure the system is working as expected. If the system is not performing as well as expected, corrective action should be taken as soon as possible. To ensure that the evaluation is unbiased, system operators should consider using a third-party to conduct the evaluation and monitoring.

Operational Procedures

If an agency plans to actively use QLD by either integrating it into its traffic signal operations or broadcasting it to CVs, the agency would need to update its operational procedures. As mentioned previously, QLD would require an increased level of data management in the TMC, including additional procedures for data security and data quality control. If an agency wishes to use QLD in its traffic signal operations, the agency would need to implement new algorithms and new signal timing programs that can make best use of the new data. If agencies wish to push this data out to CVs, they would need procedures in place to make sure the data is properly formatted in the correct message and broadcast in a standard (e.g., Road Safety Message, SPaT, or MAP) that can be used by vehicles. Finally, in order to ensure the lead agency is receiving trusted data from vehicles, the lead agency would need to adopt a SCMS that is interoperable with the broader CV network. Once in place, the SCMS system may not remain stagnant; regular testing and feedback from the industry would be required.

Outreach

As agencies begin to deploy QLD systems (or any new CV application for that matter), they would want to implement a program of internal and external outreach. As described previously in the staffing and training section, QLD systems would have an impact on lead agency staff responsibilities. Public information specialists should be brought into the project early so that they can understand the technology and are able to communicate it to the public. Agencies should also have a mechanism for communicating with the car manufacturers and technology providers since the agencies would all be sharing QLD data and have a common interest in its success. For this outreach to be successful, agencies would need to develop and execute a comprehensive communications plan as the QLD systems is rolled out.

Policies

Implementation of QLD may require new policies by the operating agency. As stated previously, if QLD data were used by vehicles for either informational purposes or control, the data would need to be secure and reliable, which would likely require stricter policies to ensure data security and provide assurance that the data is trusted. Agencies would also need to establish a policy on data archiving and protecting privacy. Agencies may want to consider a new policy that requires that all CV data be part of an SCMS. QLD is currently only an optional and somewhat unclear field in the SPaT message set; additional work is needed to define the standard and possibly to expand where the data is housed. Finally, in order for QLD to work as defined in this ConOps, a CV environment must exist that includes in-vehicle equipment, shared data, and digitized information coming from the infrastructure. The successful role out of this CV environment may require new policies to mandate or incentivize deployment of CV technology in both infrastructure and vehicles.

7.3 Impacts During Development

Several impacts should be considered during development of the QLD systems. These impacts include, but are not limited to the following:

- Acquiring the proper permits for deploying CV technology. Federal Communications System licensing, if new wireless communications technologies are deployed
- Evolution of wireless communications technologies
- Improvements in queue detection system technologies
- Public outreach and acceptance

8.0 Analysis of the Proposed Concept

8.1 Summary of Improvements

These data sets weren’t available at the resolution of the QLD system proposed. Having the data available would enable applications in a CV environment that were previously not possible.

Traffic management capabilities may improve if system operators are able to take advantage of data coming from QLD systems to optimize the transportation network.

8.2 Disadvantages and Limitations

QLS data may not always be available or accurate, and CV penetration rate on roadways may vary widely.

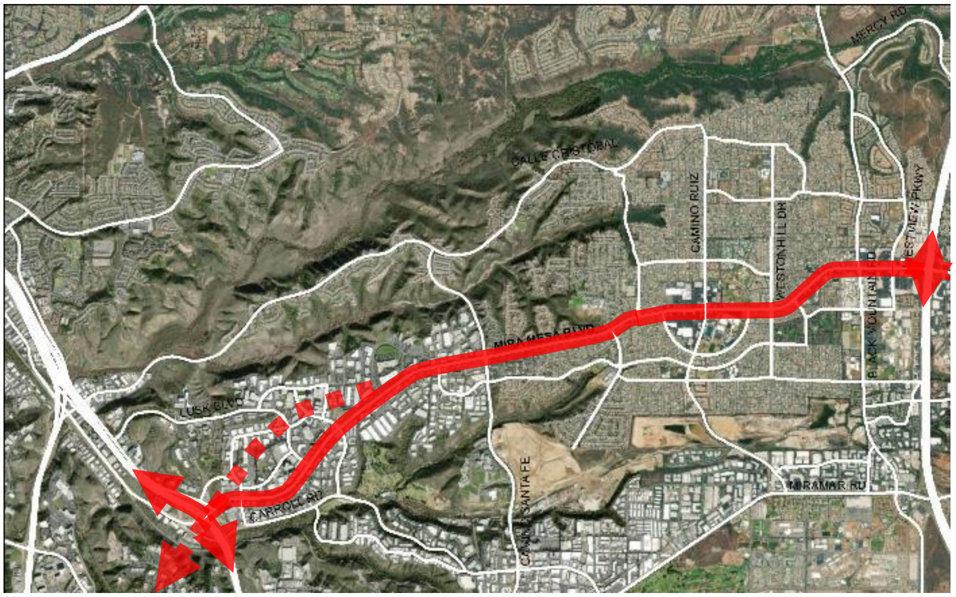
Using video inspection for QLD validation is time consuming and difficult. Using other validation methods like radar, or in-pavement detection may not provide the data at the same resolution.

8.3 Alternatives and Tradeoffs Considered

Some use cases may assume this data exchange would occur without cost and others may assume a cost associated with obtaining the data from the vehicles.

9.0 Notes

Appendix A: Images of Typical Arterial Corridors



Appendix B: Stakeholder Interview Summary

CTCS, QLD ConOps – Stakeholder Outreach Interview Summary
October 2019

Approach
The project panel requested that the project team reach out to additional stakeholders for feedback to support the Connected Traffic Control Systems (CTCS) project. A list of stakeholders was identified with stakeholder types that were intentionally diverse, ranging from industry organizations, automakers, technology providers, ITS device and traffic signal control vendors, academic researchers, and local departments of transportation. Interview requests were sent to eight stakeholders, six responses were received, and five interviews were conducted from October 21 to 25, 2019. Stakeholders responded to an email request sent by the project team for the interview and the project team worked with the stakeholders who responded to set up a time to discuss the Queue Length Detection (QLD) concept. See Appendix B.1 for the information that was provided to the stakeholders.

Method
The primary objective for each interview was to A) review and request feedback on the QLD concept; B) confirm user needs; and C) discuss operational scenarios. Interviewees were not asked to prepare for the call in advance by reading any specific materials, although the project information, including deliverables for Tasks 1-4, were typically provided in advance of the call. Appendix B.3 shows a summary of interviews conducted.

Each call was scheduled for just 30 minutes. Overall the calls were fairly informal and began with a basic description of the CTCS project, and QLD as one of the research areas of the project's research road map that was undergoing additional exploration through the development of a Concept of Operations. At that point the interviewee was asked if they had questions or comments and the discussion began. Toward the end of the call, the project team attempted to ask each stakeholder for details on how they thought this information would best be disseminated and also for their opinion on if QLD would be used in safety critical applications or mobility applications (or somewhere in between).

Outcomes:
Recurring Themes
A number of key themes came up in multiple interviews, as described below and in Appendix B.4:

1. Detailed queue information is needed; however, the data can be presented in several ways. There is also the back of the queue location, if that length is increasing or decreasing, is the queue stopped or slowly moving, classification of vehicles, acceleration rates of other vehicles, presence of pedestrians. Lane specific information is absolutely critical. The required accuracy of this information is unclear at this time. There are a lot of assumptions being made: arrival rates, known traffic signal system patterns, initial length of queue at the start of the cycle, current status of the signal. Queue increase rate / queue spillback are especially critical factors.
2. Data would be processed at the edge. The data would not go back to the system operator or central system to process the data, it must be calculated in real-time at the intersection and then can be shared with the system operator.
3. Agreement that benefits would be realized even with a small percentage (5-10%) of connected vehicles (CVs) able to help with QLD calculations.
4. If/when all vehicles become connected, then operational strategies at intersections changes drastically to become slot-based and more like air traffic control. While not stated explicitly, this is

clearly the end goal for those deeply involved with these efforts due to the potential benefits associated with machine-to-machine applications.

5. Arterial streets are designed to have queues and unmet demand due to signal timing. Signals do plan for queues and provide storage for queues. Queues are not so bad. Critical information such as if the queue is exceeding planned storage areas is important.
6. A lot can be done with current ITS detection systems.
7. QLD has a strong linkage with travel time information.
8. QLD must optimize the entire corridor / CV environment, not just one signal.

Unique Perspectives

A few unique ideas were discussed:

1. Merging QLD with some third-party data may be difficult because the time scale, frequency, and spatial measurements are so different. For example, Inrix travel times are tied to Traffic Message Channel segments, which make the data easier to measure and use. How would QLD translate into a TMC system at a large scale, which has segments much larger than the desired queue length resolution?
2. NoTraffic is able to produce QLD information through its current system and would not likely use additional info if it were available.
3. Operational goals for corridors are emerging to move as many people through a corridor as possible (instead of vehicles), so vehicles with more passengers would have priority.
4. QLD relates strongly to many projects that Contra Costa Transportation Authority already has underway. Signal info is being integrated into private vehicles, as well as shared Automated Vehicle shuttles. There is also project underway that would provide more green time to transit vehicles with more passengers through integration with transit CAD/AVL systems. GoMentum station has the ability to test the concept with six different controllers and DSRC vendors. The Innovate680 project would require advanced ramp metering to accommodate bus on shoulder operations that would need to hold the ramp meter while transit vehicles pass, while optimizing the system as a whole.
5. MMITSS Phase I in the Anthem Test Bed used real-time QLD from CVs with the RSU receiving BSM and doing the processing on the RSU.
6. Expect it to be challenging to validate QLD results. It is fairly straightforward to do the computations and getting the values, but the data would be hard to validate. Videos can be used, but it is costly to spend the time doing that analysis.

Specific user needs / Operational scenarios

Several specific user needs and operational scenarios emerged during the interviews:

1. Consider the lessons learned with the EDCM (Event-Driven Configurable Messaging) project, which focuses on sending only changing information and does not send the same information all the time. They also associate a priority or an urgency of the information. This relates to QLD because special messages should be sent when a vehicle is at the end of the queue; this message should be louder. QLD should be designed in a way that does not overload the system with unnecessary information.
2. What happens to the systems when the front of the queue is not at the stop bar? For example, a stalled car or closed lane prior to the intersection?
3. First responder scenarios – determine how long it would take to flush the system in oversaturated conditions.

4. Some cities are very focused on roundabout. How would this work in coordination and/or at roundabouts?
5. How do you know a fire truck or vehicle getting EVP / TSP is official? Security associated with connected vehicles can help with this – even through just the BSM.
6. iPEMS / ClearGuide / Systems performance measurements. Queue length is already being calculated through speed data or loop detectors, not at as good of resolution as connected vehicles. Could improve the accuracy of the intersection. Adding a CV element would be interesting to the evolution of performance measures.

Appendix B.1: Meeting Invite

Join by phone

Conference call information was provided.

Objectives

1. QLD concept review and feedback
2. Confirm user needs
3. Discuss operational scenarios

Overview

On behalf of the Connected Vehicle Pooled Fund Study's Connected Traffic Control Systems (CTCS) project, WSP is seeking this stakeholder input to help guide one of the project deliverables. This interview has been designed to be a short 30-minute discussion regarding an arterial focused Queue Length Detection (QLD) concept.

For your reference, please see below for a project description:

Connected Traffic Control System (CTCS): Research Planning and Concept Development (website)
Conducted by WSP USA (PI: Tom Timcho)

The goal of this project is to develop the research plan of the Connected Traffic Control System (CTCS) with prioritized research areas, and develop the concept of operations (ConOps) of the high-priority research area(s).

The objectives of this project are:

- To review the existing studies and developments and engage with stakeholders to identify the needs of the current traffic control systems as Connected Automated Vehicles (CAVs) become more common, and map the potential benefits that can be achieved under CTCS.
- To engage, coordinate and collaborate with other stakeholders, including other researchers, infrastructure owner operations staff, deployers, traffic signal control vendors, standards groups, vehicle systems representatives like the Crash Avoidance Metrics Partners (CAMP) and other Original Equipment Manufacturers (OEMs), to avoid duplication where possible and enhance research outcomes through validation of needs and constraints.
- To develop the CTCS research plan and provide supporting information to enable assessment and prioritization of continued short- and longer-term research and development strategy.
- To develop a CTCS ConOps of the high-priority research area(s) that comprehends the entire roadway system (i.e., considering traffic signals along arterials, interactions with ramp terminals, and ultimately freeway facilities from a multi-modal perspective that considers connected automation).

Tasks

- Task 1: Project Management Plan
- Task 2: Stakeholder Engagement Planning for Research
- Task 3: Research Review
- Task 4: Assessment of Technology Readiness Levels for Priority Research Areas
- Task 5: Development of CTCS Research Plan
- Task 6: Development of Concept of Operations of High-Priority Research Areas

Appendix B.2: Interview Framework

- **General Project Information (5min)**
  - CV PFS
  - CTCS Work Plan and Previous Tasks

- **ConOps Overview (10min)**
  - Section 1 (Purpose)
  - Section 2 (Scope)
  - Section 4 (Background)

- **Vision (5min, as needed)**
  - Section 5 (Concept)
  - Section 11 (Operational Scenarios)

- **Impacts (5min, as needed)**
  - Section 6 (User-Oriented Operational Description)
  - Section 7 (Operational Needs/Goal/Vision)

- **Other Comments? (10min)**
  - Discuss relevant sections as appropriate
  - General feedback and discussion

- **Reference Materials?**
  - List any reference materials that were discussed.

- **Additional Interview Details (Complete after the interview)**
  - Tone of meeting
  - Is the concept clear?
  - Quality of feedback?
  - Additional leads or next steps?

Appendix B.3 List of Interviews Conducted

DATE	SYSTEM USER TYPE	COMPANY	NAME	EMAIL
10/21/19	Research Group	Texas Transportation Institute	Geza Pesti	g-pesti@tamu.edu
10/22/19	Technology Provider (Data Fusion)	NoTraffic	Tal Kreisler	tal@notraffic.tech
10/23/10	Industry Groups / Automakers	CAMP / Nissan	Roy Goudy Richard Deering Shah Hussain Kevin Balke Hendrik Guenther David Florence	goudyr1@NRD.NISSAN-USA.COM rkdeering01@gmail.com shussain@campllc.org K-Balke@tti.tamu.edu Hendrik-Joern.Guenther@vw.com d-florence@tti.tamu.edu
10/24/19	ITS Device and Traffic Signal Control Vendors	Iteris	Shayan Khoshmagham Ram Kandarpa	sxk@iteris.com rkandarpa@iteris.com
10/24/19	State and Local DOTs	Contra Costa Transportation Authority	Tim Haile	thaile@ccta.net

Appendix B.4 Key Themes by Interviewee

COMMON THEME REPORTED	STATE AND LOCAL DOTS	ITS DEVICE AND TRAFFIC SIGNAL CONTROL VENDORS	INDUSTRY GROUPS / AUTOMAKERS / RESEARCHERS	INDUSTRY GROUPS / AUTOMAKERS / RESEARCHERS	TECHNOLOGY PROVIDER (DATA FUSION)
	Contra Costa Transportation Authority	**Iteris**	**CAMP / Nissan**	**Texas Transportation Institute**	**No Traffic**
Detailed queue information is needed, and it can be sliced and diced in many ways...	X	X	X	X	X
Data would be processed at the edge…		X	X	X	X
Agreement that benefits would be realized even with a small percentage (5-10%) of connected vehicles ….	X	X	X	X	X
If/when all vehicles become connected, then operational strategies change…		X	X	X	X
Arterial streets are designed to have queues and unmet demand due to signal timing…		X	X	X	X
A lot can be done with current ITS detection systems...		X			X
QLD has a strong linkage with travel time information…	X	X		X	X
QLD must optimize the entire corridor / connected vehicle environment, not just one signal…	X	X	X	X	X